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An Automated Test of Fitts' Law and Effects of Target Width and Control/Display Gain Using a Digitizer Tablet

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The present study employed a subject-paced target positioning task embodied in a digitizer-microcomputer-CRT configuration. The response distributions around the target areas were examined and the response normality hypothesis could not be rejected. However, an alternative hypothesis that assumed the corrected Fitts' ID (Index of Difficulty) computed from the effective target width and average movement amplitude would be a better predictor of movement time than the uncorrected ID could not be accepted. Although Fitts' Law was not the best movement time model for the data of the present study, Fitts' Law was found to be a useful movement time model when direct visual feedback of control movements is available or the feedback of control movements is provided by an indicator with a unique control-display gain on the display. When direct visual feedback of control movements was available, control target width was found to be an important variable which could affect motor performance independently of ID values. When the feedback of control movements was provided on a display and more than one control-display gain was included, in addition to Fitts' ID, control target width, display target width, movement amplitude, and the interactions between control target width and other variables may all have significant effects on motor performance. The results of analysis of variance indicated that movement amplitude, display target width, control target width, and the interactions between control target width and other variables were all important factors that could affect motor performance. It has also been demonstrated that the numeric value of C/D gain did not have a systematic effect on human motor performance. Instead, the effect was probably the combination of control target width and display target width effects. Finally, the effective control target widths were computed from the standard deviations of response distributions, and their potential usefulness in specifying the active control target areas and the inter-target displacements (or the deadspace around an active control target area) was discussed.

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INTRODUCTION

Motor performance in relation to response magnitude and response variability has been one of the most widely studied topics in human factors and experimental psychology. Following Shannon and Weaver's indication (1949) that information theory could be applied to psychological problems, an information-processing model combined with information theory has become a very popular approach to the study of human performance. Fitts (1954, 1964, 1966) was one of the earliest and most influential proponents of this approach. He extended information theory to the human motor system and proposed that the information capacity of the motor system can be interpreted as analogous to Shannon's Theorem 17 which is:[1]

$$C = B * \log (P+N)/N \text{ (in bits/second)}$$

where

B = Bandwidth,

C = Maximum channel capacity,

P = Average power of transmitted signal,

N = Average power of white Gaussian noise.

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[1] The logarithms used in this paper are always taken to base 2.

Fitts(1954) reasoned that the average amplitude (A) of a human movement is equivalent to average signal plus noise power (P+N) and that half the range of movement variability (i.e., half the target width) is equivalent to average noise power (N). Thus, the channel capacity (C) or the Index of Performance (IP) proposed by Fitts is given by:[2]

C (or IP) = (1/MT) * log A/(W/2) (in bits/second)

where

1/MT = the reciprocal of movement time (in cycles/second).

In a series of investigations (Fitts, 1954; 1964; 1966) of the relation between the variables of target width (W), movement amplitude (A), movement time (MT), and accuracy involved in the reciprocal-tapping, pin-transfer, and disk-transfer tasks, Fitts developed an Index of Difficulty (ID) and defined it as log (2A/W) (in bits/response) which, from his point of view, was the degree of control required over the organization of a response or the amount of information required to specify a response. The major findings of his studies (Fitts, 1954; 1964; 1966) are summarized as follows:

[2]Although Fitts has indicated that his analogy with Shannon's Theorem 17 was not exact, most researchers accept the analogy and employ the Index of Performance (IP) or channel capacity of the motor system (C) as a valid information-theory measure. Recently, Fitts' analogy has been argued by Kvalseth (1979; 1980; 1981).

1. Within limits,[3] the information capacity of the human motor system is relatively constant and this is the result of a limited channel capacity of the motor system;
2. The Index of Difficulty (ID) is the major factor limiting the rate of motor performance and its effect can be represented by a simple equation known as Fitts' Law:

$$MT(seconds) = a + b * ID$$

   where a is an empirically determined constant; b is the reciprocal of the Index of Performance (IP) which expresses the results as a performance rate (in bits/second);
3. Within limits, the performance rate (IP) is equivalent for tasks of the same ID and independent of the target width and movement amplitude from which the ID is calculated;
4. Fitts' Law holds for both serial and discrete responses. However, the slope (b) of Fitts' Law is less steep for discrete than for serial responses and therefore the discrete task has a higher channel capacity;

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[3] These are the limits for movement amplitudes which are 4-8 in. and more consistently associate with good performance (Fitts, 1954).

5. Reaction time and movement time are influenced quite independently by the degree of uncertainty regarding the stimulus to a movement and the degree of uncertainty permitted in executing the movement;
6. The motor system is relatively more efficient in producing low-information (i.e., under small ID conditions) than high-information (i.e., under large ID conditions) movements;
7. The rate of information processing by the motor system remains relatively constant under different preparation conditions (i.e., subject-paced vs. two-choice responses) and with different cognitive sets (i.e., speed vs. accuracy).

Fitts' Law has been replicated successfully by numerous researchers (Annett, Golby, & Kay, 1958; Crossman, 1960; Knight & Dagnall, 1967; Welford, 1968; Hancock, Langolf, & Clark, 1973; Drury, 1975; Langolf, Chaffin, & Foulke, 1976; Card, English, & Burr, 1978; Jagacinski, & Monk, 1985) involving a diversity of tasks and over a wide range of movement amplitudes and target widths. Despite the fact that Fitts' Law provides a relatively accurate prediction of movement time, some limitations and assumptions must be considered when applying it to the human motor system.

1. The motor system is defined as including only direct visual feedback and proprioceptive feedback from control movements (Fitts, 1954);
2. The responses must be uniform and highly overlearned (Fitts, 1954);
3. The target must be static (Jagacinski, Repperger, Ward, & Moran, 1980); and
4. The target width (W) and movement amplitude (A) expressed in the Index of Difficulty (ID) are assumed to be the effective target width and effective movement amplitude. An effective target width includes 96 percent or plus and minus 2.066 standard-score unit hits (i.e., correct positionings); and the hits around the center of each target are normally distributed. An effective movement amplitude is the average movement amplitude calculated from all the responses (Crossman, 1960; Welford, 1968).

Although there is no doubt about the validity of Fitts' Law, the human control mechanisms that account for this validity still remain controversial. In addition to Fitts' information theory explanation, a variety of alternative models of movement time have been developed. These models include the Velocity Control Model (Crossman & Goodeve, 1963), the Discrete Feedback Model (Crossman & Goodeve, 1963; Keele, 1968), Nonlinear Models (Langolf, Chaffin, & Foulke, 1976), the Movement-Output Variability Model (Schmidt, Zelaznik, & Frank, 1978; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979; Meyer, Smith, & Right, 1982), and the Power Law Model (Kvalseth, 1979; 1980; 1981). Although the three latest models appear to be more appealing due to the use of more advanced experimental apparatus or more rigorous experimental paradigms, the controversy is still not settled. However, the disagreement on the movement time models does not affect the generality of predictions from Fitts' Law which still provides a reasonably close and parsimonious approximation to the actual movement time data.

When visual feedback of control movements is provided by a display, motor performance is frequently assumed to be related to the ratio of the magnitude of the control movement to the magnitude of the movement which occurs on the display. This relation is often referred as "control-display ratio" or C/D ratio and its reciprocal is known as "control-display gain" or C/D gain. Early studies (Jenkins & Connor, 1949; Jenkins & Olson, 1952; Jenkins & Karr, 1954; Gibbs, 1962) have suggested that an optimum C/D gain could be found to balance the trade-offs between gross movement time and fine adjustment time which are associated with control positioning. They found that high C/D gains (low C/D ratios) could reduce gross movement time but also increase fine adjustment time. Although all the researchers agree that there is no C/D gain that is optimum for all circumstances, most believe that for a given continuous control-display interface there will be an optimum C/D gain. One of the most recent guidelines on C/D ratio (or C/D gain) was provided by McCormick and Sanders (1982). They state:

> The numeric value for the optimum C/D ratio is a function of the type of control (knob, lever, crank, etc.), size of the display, tolerance permitted in setting the control, and other system parameters such as lag. Unfortunately, there are no formulas for determining what C/D ratio would be optimum for given circumstances. Rather, this ratio should be determined experimentally for the control and display being contemplated. (p. 256)

C/D gain has been recognized as one of the important factors in the design of continuous control-display interfaces.

Several researchers (Langolf, Chaffin, & Foulke, 1976; Sheridan, 1979; Buck, 1980) have noticed that the effects of target width on motor performance might have been overlooked when considering the effects of Fitts' ID or the effects of control-display gains. Sheridan (1979) examined Fitts' data (1954) and found that tasks with smaller target widths and movement amplitudes showed longer movement times than tasks with equivalent

IDs but having larger target widths and movement amplitudes. Since it was unlikely that smaller amplitudes increased movement times, Sheridan (1979) reasoned that target width alone could affect movement time independently of ID values. We can confirm Sheridan's reasoning by referring to Langolf, Chaffin, and Foulke's findings (1976). Langolf et al. (1976) analyzed motion trajectories and found that when movement amplitude was held constant the whole movement toward target center became slower when target width was reduced. However, when target width was held constant the whole movement toward target center became faster when movement amplitude was reduced. So, under equivalent ID conditions, the longer movement times associated with the ID values with smaller target widths and smaller amplitudes were the net effects of slower movements caused by the smaller target widths and faster movements caused by the smaller movement amplitudes. Such net effects implied that target width effects were more significant than movement amplitude effects under equivalent ID conditions. Sheridan (1979) further argued that the constant weighting of factors (i.e., A and W) over a variety of tasks proposed by Fitts' Law was ill-founded, and that the weighting of these factors should be changed depending on whether the task involved ballistic movements controlled by effector mechanisms or controlled movements mediated by decision mechanisms. In his opinion, movement amplitude was thought to be of major importance in simple ballistic tasks, while target width was of major importance in controlled tasks (Sheridan, 1979).

Buck (1980) let his subjects perform a self-paced, step-input, pursuit tracking task using a joystick-oscilloscope system with different C/D gains and studied the effects of control target width (i.e., target width on the joystick) and display target width (i.e., target width on the oscilloscope) on motor performance. He found that both control and display target widths (but not C/D gains) affected performance time. Overshoot Time (fine adjustment time) was affected by both control and display target widths, while acquisition time (gross movement time) was affected only by the control target width. Buck (1980) questioned the effects of C/D gains by arguing that previous studies (Jenkins & Connor, 1949; Gibbs, 1962) manipulated C/D gains by changing the amount of control movement and keeping the display constant. He felt that it was the changes of the tolerance on control devices that affected motor performance. According to Buck's (1980) argument, we can infer that when the display target width is held constant, increasing control target width decreases the C/D gain and enhances motor performance. In contrast, when the control target width remains unchanged, increasing display target width increases the C/D gain and also improves motor performance. Thus, the numerical values of C/D gain may really have no systematic effect on motor performance.

It is interesting to use Fitts' Law to examine Buck's movement time data. There were five experimental conditions in Buck's study and four of them had an ID value of 5.155; one had an ID value of 6.155. Buck's data indicated, in terms of Fitts' Law, that the performance rate (IP) was around 10 bits/second which has been found in a large number of studies on motor performance and the difference between Buck's data and Fitts' Law prediction would not exceed the difference caused by a 1-bit change in ID.[4] Fitts' Law again shows a good prediction in movement time.

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[4] If the performance rate was assumed to be 10 bits/second, then a 1-bit change in ID would result in about 100 msec change in movement time.

Hypotheses

The present study used a digitizer-microcomputer-CRT configuration to examine the effects of C/D gains, ID values, and the effects of control and display target widths on motor performance. It was hypothesized that display target width, which provided the visual feedback of control movements, would affect fine adjustment time (but not gross movement time), while control target width would affect both gross movement time and fine adjustment time. It was also hypothesized that control-display gains would not produce any systematic effect on movement time. Rather, the differences, if any, under different C/D gain conditions were expected to be due to control target width and display target width effects.

Because previous studies (Hancock et al., 1973; Langolf et al., 1976; and Card et al., 1978) had suggested that Fitts' Law could provide a relatively good fit to data when the visual feedback of control movements was provided indirectly from a display device, ID values and movement times were predicted to be highly correlated in this study and therefore most of the variance in mean movement time would be accounted for by ID values. In addition, it was hypothesized that ID values would prove to be an important factor in the design of continuous control-display interfaces.

Although it was not the intention to study the actual control mechanisms involved in Fitts' Law in the present study, an attempt was made to estimate the extent to which movement time was actually determined by corrected IDs calculated from effective target widths and average movement amplitudes. It was hypothesized that mean movement times would be more closely correlated with corrected IDs than with uncorrected IDs.

METHOD

The present study employed a subject-paced cursor positioning task embodied in a digitizer-microcomputer-CRT configuration. Three levels of movement amplitude and two levels of each control target width and display target width were considered and their effects on movement time were examined. In addition to the four experimental groups, there were two control groups in which subjects were provided with direct visual feedback of control movements from the digitizing tablet with the target marked on it. The tablet was used to detect control movements and generate x-y coordinates which were then translated by a microcomputer, depending on predetermined C/D gains, into the corresponding x-y coordinates indicated by a cross hair cursor on the CRT screen.

Subjects

Thirty six subjects were used in this study. The subjects were right-handed male and female students recruited from the University of South Dakota. Subjects received extra credit points for their participation in the experiment. All potential subjects were tested for visual acuity and only those with 20/20 or better visual acuity and with no previous experience working with a digitizing tablet were accepted.

Apparatus

An Elographics, Inc. Model E233 H/GT digitizing tablet with a 300 mm x 300 mm active surface area was used for the study. The E233 tablet required approximately 4 oz. activation force, providing resolution of approximately 1 part in 4000, and showing a typical standard deviation of error of 1 mm. The E233 was interfaced to the microcomputer through an Elographics, Inc. Model E271-60 general purpose controller which detected touch-downs on the tablet, converted x and y analog signals to digital position coordinates, and verified data transmitted to the microcomputer. The x-y coordinates from the digitizer were sampled at a baud rate of 2400 (approximately 22 x-y coordinates were sampled per second). The controller/microcomputer interface was accomplished by means of an RS232 serial interface. Since the tablet could be actuated by any pointing device, a commercially available X-ACTO burnisher with a 1.59 mm ball end was used as a pointing stylus to reduce "fall-out" errors[5] which had been noticed by previous studies using an unaided finger as a pointing device (Whitfield, Ball, & Bird, 1983; Ellingstad, Parng, Gehlen, Swierenga, & Auflick, 1985).

An Amdec Color II RGB monitor with a resolution of 640 X 200 was used as a display device. Only monochromatic displays were employed. The microcomputer system used to support the tablet and display was an IBM 5150 PC system equipped with 256KB RAM, two double-sided, dual density 320KB flexible disk drives, AST Six-Pak (serial & parallel I/O & hardware clock), and an Okidata 83A dot matrix printer. Software to support the experiment was written in Turbo Pascal.

Experimental Design

A mixed-factors, repeated measures design was used. Each subject was tested under one C/D gain condition only in order to avoid possible unbalanced transfer effects. The control target width (wide: 8 mm vs. narrow: 4 mm) and display target width (wide: 9 mm vs. narrow: 4 mm) served as between subjects variables:

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[5] A "fall-out" error occured when a subject drifts off target because (a) the contact area between the pointing stylus and the digitizing tablet is too large and/or (b) the stylus is not lifted off of the tablet vertically.

Each subject was tested with three different movement amplitudes (i.e., 24 mm, 48 mm, & 96 mm) and therefore the movement amplitude was treated as a within subjects variable. In addition, two control groups with the target marked on the tablet were also included. The combinations of the above target widths and movement amplitudes produced four ID values (2.585, 3.585, 4.585, & 5.585), four C/D gains (0.500, 1.000, 1.125, & 2.250), and 18 experimental conditions (see Table 1).

Procedure

Three male and three female subjects were randomly assigned to each of the six groups. Subjects were seated in front of a digitizer-CRT system. Each trial consisted of one target positioning. At the begining of a trial, the subject held the stylus on the starting point, designated on the right side of the tablet, for a brief period of time. Then the word "ready" would appear below the starting point on the CRT, and at the same time a "beep" would sound. After the word "ready" appeared on the screen, the subject could lift-off the stylus from the starting point on the tablet to move the stylus/cursor[6] to the target area. When the

[6] Subjects in experimental groups made the responses by looking at the cursor and the target area on the screen. However, subjects in control groups made the responses by looking at the stylus and the target area marked on the touch tablet.

TABLE 1

The Experimental Design

1.A: Two Control Groups

	A1 (24mm)	A2 (48mm)	A3 (96mm)
CW1 (4mm)	G1	G1	G1
ID	3.585	4.585	5.585
CW2 (8mm)	G2	G2	G2
ID	2.585	3.585	4.585

1.B: Four Experimental Groups

		A1 (24mm)	A2 (48mm)	A3 (96mm)	C/D
CW1 (4mm)	DW1 (4mm)	G3	G3	G3	1.000
	DW2 (9mm)	G4	G4	G4	2.250
	ID	3.585	4.585	5.585	
CW2 (8mm)	DW1 (4mm)	G5	G5	G5	0.500
	DW2 (9mm)	G6	G6	G6	1.125
	ID	2.585	3.585	4.585	

CW = Control Target Width
DW = Display Target Width
A = Movement Amplitude
ID = Index of Difficulty
C/D = Control-Display Gain
G1-G6 = Group1-Group6

subject placed the stylus back on the tablet, he/she had to decide whether the stylus/cursor was within the target area. If it was on target the subject could lift the stylus off the tablet to end the trial. Otherwise, he/she had to maintain the stylus on the tablet surface and move it until the stylus/cursor was within the target area. After the stylus/cursor was moved into the target area, the subject could lift-off the stylus to complete the trial. Subjects were instructed that they could take as long as they desired to prepare for each movement. However, they were told to respond as quickly and accurately as possible once the movement was initiated (i.e., the stylus was lifted-off from the starting point). A block consisted of 15 consecutive trials in the same level of movement amplitude. After the first 6 blocks of practice/warmup trials, each subject was tested for 6 blocks in each level of movement amplitude in a random and counterbalanced order[7] with a total of 18 blocks or 270 trials in one session. Each subject was tested in two sessions and there was a ten-minute break between the two sessions. The average movement times were first obtained from two control groups and these data were used as the feedback of optimal performance for the

[7] There were six possible permutations of three levels of movement amplitude. The order of 18 blocks of trials were randomly and exclusively selected from the six possible permutations.

subjects in experimental groups. At the end of each block, subjects were given feedback on (a) the movement time taken for each trial, (b) the differences between (a) and the optimal movement time obtained from control groups, (c) number of correct touch-downs of gross movements, and (d) number of correct final selections. The experimental procedure took approximately one to two hours for each subject.

Performance Measures and Data Analysis

Three categories of dependent measures were recorded:

1. Positioning Accuracy: The positioning accuracy of gross movements (R1) and final selections (R2) were recorded. An error consisted of an incorrect target positioning of which the registered x coordinate of this positioning was not within the specified range of x coordinates. Only one dimension of movement accuracy (i.e., x axis) was of interest in this study;
2. Trial completion Time: This measure was divided into three parts:

   (a) Preparation Time (PT): Time taken from the initial positioning on the starting point to the initial lift-off of the stylus from the starting point,

(b) Gross Movement Time (GMT): Time taken from the initial lift-off to the touch-down of the stylus on the tablet,

(c) Fine Adjustment Time (FAT): Time taken from the touch-down to final positioning and lift-off.

In addition, movement time (MT) was referred as the summation of GMT and FAT;

3. The x-y coordinates of R1 and R2 on the tablet: These data were used to calculate the effective target widths (i.e., WE1 & WE2), average movement amplitudes (i.e., MNA1 & MNA2) and corrected ID values (i.e., ID1 & ID2).

Mean R1s, R2s, PTs, MTs, GMTs, and FATs were calculated separately for each subject for each of the three levels of movement amplitude under each session. The analyses of variance were performed on these mean data. The correlations between mean movement times and IDs (also corrected IDs) were examined. Furthermore, the regression equations for predicting movement times were determined.

RESULTS

Thirty six subjects were tested and each subject completed 712 trials. In order to exclude the practice/warmup effect, the response curves were examined and only 450 out of the 712 trails from each subject were included in the following analyses.

Response Variability

A test of response normality was performed on the x coordinates of the gross movements (R1) and final selections (R2) for every experimental condition. The tests, which were done by Kolomogorov D statistic using the SAS "PROC UNIVARIATE" procedure, showed that the hypothesis that these data were random samples from normal distributions could not be rejected at a significance level of 0.01. Table 2 shows the standard deviations of x coordinates of R1 (i.e., SDR1) and R2 (i.e.. SDR2), average movement amplitudes of R1 (i.e.,MNA1) and R2 (i.e., MNA2), and effective control target widths calculated from SDR1 (i.e., WE1) and SDR2 (i.e., WE2). The average amplitudes shown in Table 2 indicate that subjects tended to overshoot most of the targets. This is true because the subjects did not

TABLE 2

Response Variability Statistics

(in millimeters)

2.A: Control Groups (N = 900)

CW	AMP	MNA1	MNA2	SDR1	SDR2	WE1	WE2
4	24	25.77	25.71	0.95	0.90	3.90	3.73
4	48	50.53	50.44	1.05	0.97	4.34	3.99
4	96	98.73	98.71	1.06	1.00	4.35	4.13
8	24	25.28	25.22	1.46	1.44	6.02	5.95
8	48	50.81	50.71	1.72	1.67	7.10	6.90
8	96	98.49	98.37	1.83	1.76	7.53	7.26

2.B: Experimental Groups (N = 900)

CW	DW	AMP	MNA1	MNA2	SDR1	SDR2	WE1	WE2
4	4	24	25.91	26.69	3.88	1.75	15.99	7.21
4	4	48	48.31	49.17	6.29	1.64	25.95	6.76
4	4	96	93.14	96.45	8.59	3.52	35.45	14.53
4	9	24	25.71	25.13	4.00	1.38	16.51	5.69
4	9	48	49.45	50.72	6.68	2.09	27.53	8.62
4	9	96	95.49	96.98	10.87	1.77	44.85	7.32
8	4	24	25.23	24.87	5.84	2.49	24.08	10.26
8	4	48	47.24	48.27	7.23	2.41	29.82	9.95
8	4	96	90.88	96.19	10.63	3.88	43.84	16.01
8	9	24	26.78	26.03	3.80	2.36	15.67	9.73
8	9	48	49.41	49.28	5.79	2.61	23.86	10.75
8	9	96	96.21	96.67	8.03	2.80	33.11	11.56

Note:
Each statistic was calculated from 900 observations.

respond strictly horizontally, the way that amplitudes were measured. They tended to make responses toward themselves.

The average movement amplitudes were all very close to the amplitudes measured horizontally from the starting point to the center of the target area. However, the differences were less than 3 mm in most cases. The responses were more variable in experimental groups in which direct visual feedback of control movements was not available. Thus, the effective control target widths of experimental groups were larger than those of control groups. In general, WE1s and WE2s increased under wide control target widths (CW=8) or under large movement amplitudes or under narrow display target widths (DW=4) except that WE1s increased under wide display target widths (DW=8) when the control target width was narrow (CW=4).

Regression Analysis

Table 3 shows the means and IDs (Index of Difficulty) for every experimental condition. The "All Possible Regressions" method (Draper & Smith, 1981), in which ID values and all the variables with less than 0.15 level of significant effect were included as possible predictors, was employed to select the best

TABLE 3

Means and IDs

(second) (bits/response)

3.A: Control Groups

CW	AMP	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2	ID
4	24	0.356	0.169	0.200	0.369	0.9533	0.9567	3.585
4	48	0.392	0.227	0.203	0.430	0.8767	0.9011	4.585
4	96	0.396	0.284	0.196	0.481	0.8844	0.8967	5.585
8	24	0.283	0.088	0.183	0.271	0.9911	0.9922	2.585
8	48	0.262	0.124	0.158	0.282	0.9767	0.9789	3.585
8	96	0.300	0.178	0.165	0.343	0.9711	0.9744	4.585

3.B: Experimental Groups

CW	DW	AMP	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2	ID
4	4	24	1.269	0.288	0.858	1.146	0.4200	0.9033	3.585
4	4	48	1.425	0.370	1.023	1.393	0.2355	0.8511	4.585
4	4	96	1.530	0.456	1.046	1.502	0.1811	0.8322	5.585
4	9	24	2.434	0.239	0.882	1.120	0.5022	0.9667	3.585
4	9	48	2.452	0.312	0.989	1.301	0.3022	0.9633	4.585
4	9	96	2.755	0.439	1.145	1.584	0.2556	0.9311	5.585
8	4	24	1.141	0.334	0.799	1.133	0.5556	0.9056	2.585
8	4	48	1.193	0.391	0.870	1.260	0.4567	0.9044	3.585
8	4	96	1.216	0.448	0.956	1.404	0.2733	0.8922	4.585
8	9	24	1.752	0.217	0.562	0.779	0.7344	0.9322	2.585
8	9	48	1.777	0.267	0.721	0.988	0.5856	0.9400	3.585
8	9	96	1.774	0.334	0.774	1.107	0.4778	0.9322	4.585

regression equations for effective control target widths (WE), gross movement times (GMT), fine adjustment times (FAT), and the overall movement times (MT) for control groups and experimental groups. Each regression equation was evaluated according to the three criteria shown below:

1. The value of R^2 (the square of the multiple correlation coefficient),
2. The Mallow's Cp statistic, and
3. The subjective judgement.

These regression equations along with sample data predicted from the equations are shown in Appendix A.

As can be seen from Table 4, the hypothesis that movement times were more closely correlated with corrected ID values computed from effective control target widths and average movement amplitudes than with uncorrected ID values can not be accepted. In fact, when considering the three criteria shown before, neither corrected ID nor uncorrected ID is considered to be the only predictor that can represent the most appropriate movement time model in the study. For control groups, about 90 percent of the variance in mean GMT and about 76 percent of the variance in mean MT were accounted for by the uncorrected ID values alone. The smaller percentage of the variance in mean MT accounted for by IDs was because MT was the

TABLE 4

Correlation Coefficients Between Mean MTs and IDs

(correlation coefficients/probabilities)

4.A: Control Groups (N = 6)

	MNGMT	MNFAT	MNMT
ID1	0.9264**	0.1974	0.8388*
	0.0079	0.7077	0.0369
ID2	0.9347**	0.2185	0.8508*
	0.0063	0.6775	0.0317
ID	0.9494**	0.2571	0.8723*
	0.0038	0.6229	0.0234

4.B: Experimental Groups (N = 12)

	MNGMT	MNFAT	MNMT
ID1	0.3654	0.2380	0.2982
	0.2428	0.4563	0.3465
ID2	0.6247*	0.7300**	0.7369**
	0.0299	0.0070	0.0063
ID	0.7333**	0.8256**	0.8430**
	0.0067	0.0009	0.0006

Note:

ID1 = log (2 * MNA1 / WE1)
ID2 = log (2 * MNA2 / WE2)
* : significant at 0.05 level
** : significant at 0.01 level

summation of GMT and FAT and the mean FAT was primarily affected by the control target width (CW) and movement amplitude (AMP), not by ID values. When an additional predictor CW was added to the regression equations which consist of only uncorrected ID, more than 90 % of all the variance in mean GMT and MT that was not accounted by ID could be accounted for by CW. Furthermore, the above relative gain in unaccounted variance could reach more than 98 percent if CW is replaced by WE (effective target width). For experimental groups, uncorrected ID was still the best single predictor for predicting the movement times (including FAT). About 50-70 percent of the variance in mean movement times could be accounted for by ID values alone. Again, the best predictor alone does not represent the best model.

Analysis of Variance

Six dependent variables were considered for analyses. They were: preparation time (PT), gross movement time (GMT), fine adjustment time (FAT), the overall movement time (MT), accuracy of gross movement (R1), and accuracy of final selection (R2). Four independent variables: session (SE), amplitude (AMP), control target width (CW), and display target width (DW, considered only in experimental groups), and the interactions among them were tested. The analysis of variance was performed on both median data and mean data to detect any inconsistent results between them. The results did not show any inconsistency, thus only the results of analysis on mean data are presented. Table 5 and Table 6 show the means of all dependent variables. The significant effects found in each dependent measure are shown in Table 7 and Table 8. A summary of these effects is presented in Table 9.

TABLE 5

Means Tested with ANOVA for Control Groups

5.A: Means Tested under CW

CW	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
4	36	0.381	0.227	0.200	0.426	0.9048	0.9181
8	36	0.282	0.130	0.169	0.299	0.9796	0.9818

5.B: Means Tested under SE

SE	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
1	36	0.370	0.191	0.188	0.379	0.9344	0.9441
2	36	0.294	0.166	0.180	0.346	0.9500	0.9559

5.C: Means Tested under AMP

AMP	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
24	24	0.320	0.128	0.191	0.320	0.9722	0.9744
48	24	0.327	0.175	0.180	0.356	0.9267	0.9400
96	24	0.348	0.231	0.181	0.412	0.9278	0.9356

5.D: Means Tested under CW and AMP

CW	AMP	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
4	24	12	0.356	0.169	0.200	0.369	0.9533	0.9567
4	48	12	0.392	0.227	0.203	0.430	0.8767	0.9011
4	96	12	0.396	0.284	0.196	0.481	0.8844	0.8967
8	24	12	0.283	0.088	0.183	0.271	0.9911	0.9922
8	48	12	0.262	0.124	0.158	0.282	0.9767	0.9789
8	96	12	0.300	0.178	0.165	0.343	0.9711	0.9744

5.E: Means Tested under SE and CW

SE	CW	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
1	4	18	0.429	0.249	0.205	0.454	0.8911	0.9067
1	8	18	0.311	0.132	0.171	0.303	0.9778	0.9815
2	4	18	0.334	0.204	0.195	0.399	0.9185	0.9296
2	8	18	0.253	0.127	0.166	0.294	0.9815	0.9822

TABLE 6

Means Tested with ANOVA for Experimental Groups

6.A: Means Tested under CW

CW	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
4	72	1.977	0.350	0.990	1.341	0.3161	0.9080
8	72	1.475	0.331	0.780	1.112	0.5139	0.9178

6.B: Means Tested under DW

DW	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
4	72	1.296	0.381	0.925	1.306	0.3537	0.8815
9	72	2.157	0.301	0.845	1.147	0.4763	0.9443

6.C: Means Tested under SE

SE	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
1	72	1.756	0.357	0.899	1.256	0.4107	0.9074
2	72	1.697	0.325	0.871	1.197	0.4192	0.9183

6.D: Means Tested under AMP

AMP	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
24	48	1.649	0.269	0.775	1.045	0.5531	0.9269
48	48	1.712	0.335	0.901	1.235	0.3950	0.9147
96	48	1.819	0.419	0.980	1.399	0.2970	0.8969

6.E: Means Tested under CW and AMP

CW	AMP	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
4	24	24	1.851	0.263	0.870	1.133	0.4611	0.9350
4	48	24	1.938	0.341	1.006	1.347	0.2689	0.9072
4	96	24	2.142	0.448	1.095	1.543	0.2183	0.8816
8	24	24	1.446	0.276	0.680	0.956	0.6450	0.9189
8	48	24	1.485	0.329	0.795	1.124	0.5211	0.9222
8	96	24	1.495	0.391	0.865	1.256	0.3755	0.9122

6.F: Means Tested under CW and DW

CDG	CW	DW	N	MNPT	MNGMT	MNFAT	MNMT	MNR1	MNR2
1.000	4	4	36	1.408	0.371	0.976	1.347	0.2789	0.8622
2.250	4	9	36	2.547	0.330	1.005	1.335	0.3533	0.9537
0.500	8	4	36	1.183	0.391	0.875	1.266	0.4285	0.9007
1.125	8	9	36	1.768	0.273	0.685	0.958	0.5992	0.9348

TABLE 7

The Results of ANOVA for Control Groups

Dependent Variable	Significant Effect	F Value	Probability
PT	1. CW	F(1,10) = 5.82	p < 0.0365
GMT	1. SE	F(1,10) = 6.77	p < 0.0264
	2. AMP	F(2,20) = 40.38	p < 0.0001
	3. CW	F(1,10) = 5.73	p < 0.0377
FAT	1. CW	F(1,10) = 5.32	p < 0.0438
	2. AMP	F(2,20) = 4.25	p < 0.0290
	3. CW*AMP	F(2,20) = 5.50	p < 0.0125
MT	1. SE	F(1,10) = 9.65	p < 0.0111
	2. AMP	F(2,20) = 22.05	p < 0.0001
	3. CW	F(1,10) = 7.27	p < 0.0224
	4. CW*SE	F(1,10) = 4.84	p < 0.0525
R1	1. AMP	F(2,20) = 15.64	p < 0.0001
	2. CW	F(1,10) = 8.47	p < 0.0155
	3. CW*AMP	F(2,20) = 6.22	p < 0.0080
R2	1. AMP	F(2,20) = 8.27	p < 0.0024
	2. CW	F(1,10) = 5.87	p < 0.0359

TABLE 8

The Results of ANOVA for Experimental Groups

Dependent Variable	Significant Effect	F Value	Probability
PT	1. AMP	$F(2, 40) = 5.48$	$p < 0.0079$
	2. CW	$F(1, 20) = 5.33$	$p < 0.0318$
	3. DW	$F(1, 20) = 15.69$	$p < 0.0008$
GMT	1. SE	$F(1, 20) = 7.92$	$p < 0.0107$
	2. AMP	$F(2, 40) = 132.80$	$p < 0.0001$
	3. CW*AMP	$F(2, 40) = 7.21$	$p < 0.0021$
FAT	1. AMP	$F(2, 40) = 40.88$	$p < 0.0001$
	2. CW	$F(1, 20) = 16.48$	$p < 0.0006$
	3. CW*DW	$F(1, 20) = 4.48$	$p < 0.0470$
MT	1. SE	$F(1, 20) = 7.26$	$p < 0.0139$
	2. AMP	$F(2, 40) = 112.41$	$p < 0.0001$
	3. CW	$F(1, 20) = 10.79$	$p < 0.0037$
	4. DW	$F(1, 20) = 5.25$	$p < 0.0329$
	5. CW*DW	$F(1, 20) = 4.50$	$p < 0.0465$
R1	1. AMP	$F(2, 40) = 69.64$	$p < 0.0001$
	2. CW	$F(1, 20) = 47.29$	$p < 0.0001$
	3. DW	$F(1, 20) = 18.17$	$p < 0.0004$
	4. DW*SE	$F(1, 20) = 8.46$	$p < 0.0087$
R2	1. AMP	$F(2, 40) = 7.19$	$p < 0.0022$
	2. DW	$F(1, 20) = 5.65$	$p < 0.0275$
	3. CW*AMP	$F(2, 40) = 4.46$	$p < 0.0179$

TABLE 9

A Summary of Significant Effects on Dependent Variables

Significant Effect	Group	Dependent Variables
SE	CTRL	GMT, MT
	EXPT	GMT, MT
AMP	CTRL	FAT, GMT, MT, R1, R2(ALL BUT PT)
	EXPT	PT, GMT, FAT, MT, R1, R2(ALL)
CW	CTRL	PT, GMT, FAT, MT, R1, R2(ALL)
	EXPT	PT, FAT, MT, R1, R2(ALL BUT GMT)
DW	CTRL	**NOT APPLICABLE
	EXPT	PT, MT, R1, R2
CW*AMP	CTRL	FAT, R1
	EXPT	GMT, R2
CW*DW	CTRL	**NOT APPLICABLE
	EXPT	FAT, MT
CW*SE	CTRL	MT
	EXPT	NOT SIGNIFICANT
DW*SE	CTRL	**NOT APPLICABLE
	EXPT	R1

DISCUSSION

Applicability of Fitts' Law

The regression analysis revealed that, among all variables, Fitts' Index of Difficulty was a relatively good predictor of GMTs and MTs in control groups and a useful predictor of GMTs, FATs, and MTs in experimental groups. Fitts' Law did not, however, represent the most appropriate model for predicting the above data in the present study when an "All Possible Regressions" method was applied to find the best regression equations. For control groups, Figure 1 and Figure 2 show that, under equivalent IDs, the points in the figures with shorter movement amplitudes and smaller control target widths have larger GMTs and MTs. This indicates that control target width can affect GMTs and MTs independently of ID values. In fact, the most appropriate model for predicting GMT and MT included both ID and CW (control target width). For experimental groups, the irregular pictures shown under equivalent IDs are probably the result of a combination of effects of movement amplitudes, control target widths, display target widths, and other interaction

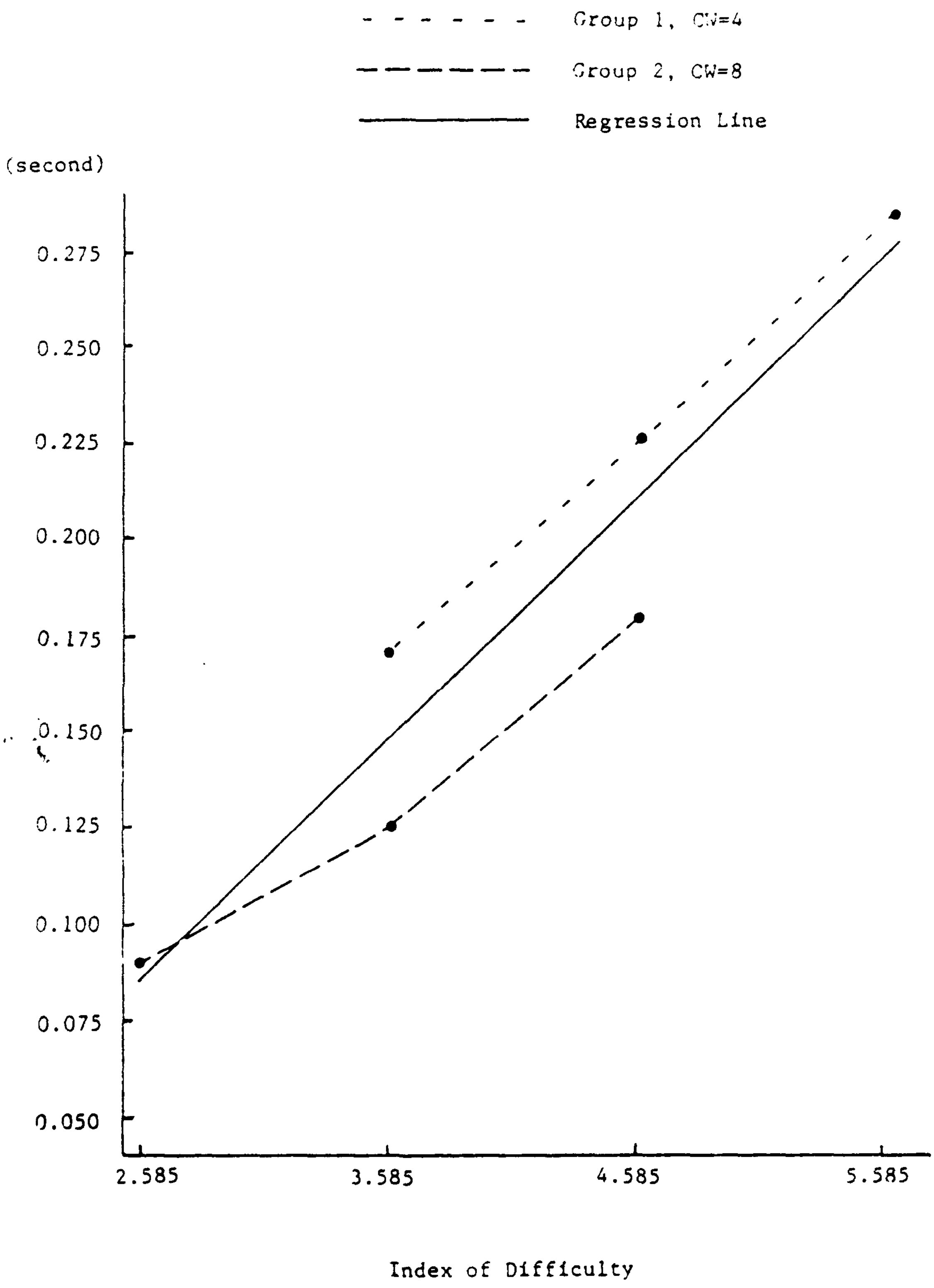

Figure 1: Mean GMTs Plotted Against IDs for Control Groups

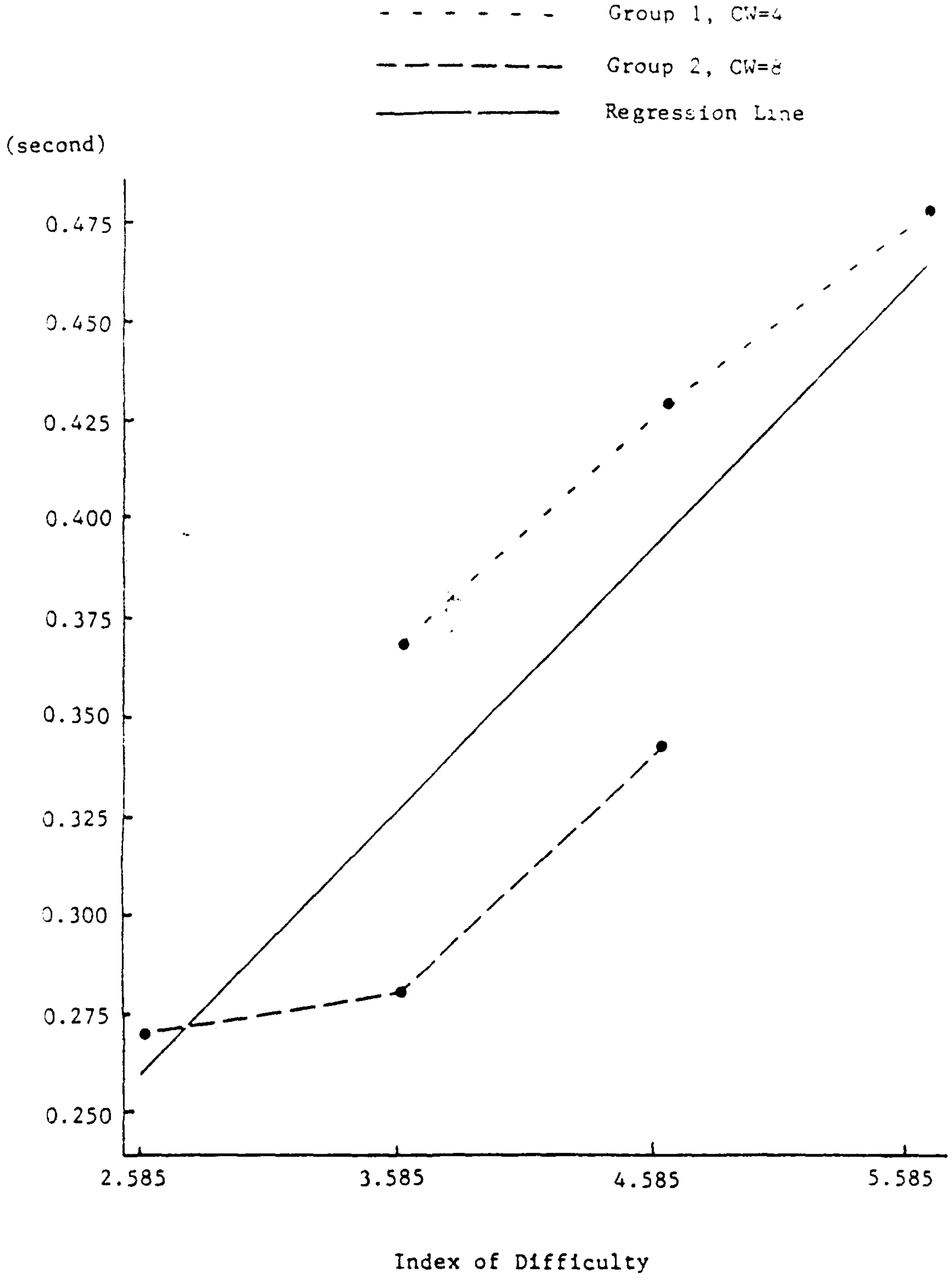

Figure 2: Mean MTs Plotted Against IDs for Control Groups

effects. ID value alone is no longer able to fully explain these complicated pictures which can be seen in Figure 3, 4, and 5. Table 10 shows the regression equation constants for the regression lines drawn in Figure 1, 2, 3, 4, and 5.

One interesting observation from these figures is that there seems to be a stronger linear relationship between ID and movement times (i.e., GMT, FAT, and MT) when each group is considered separately. In other words, ID might provide a better linear fit to the movement time data when only one unique control-display gain is considered.

In general, Fitts' Law was found to be a useful movement time model when direct visual feedback of control movements was available or the feedback of control movements was provided by an indicator with a unique control-display gain on the display.

Analysis of Variance

Among all the significant effects shown in Table 9, AMP and CW effects are the most prevalent and important ones. AMP affected not only movement time but also movement accuracy. Thus, it is important to organize a sequence of responses in the space in which each each response is made within the vicinity of the next

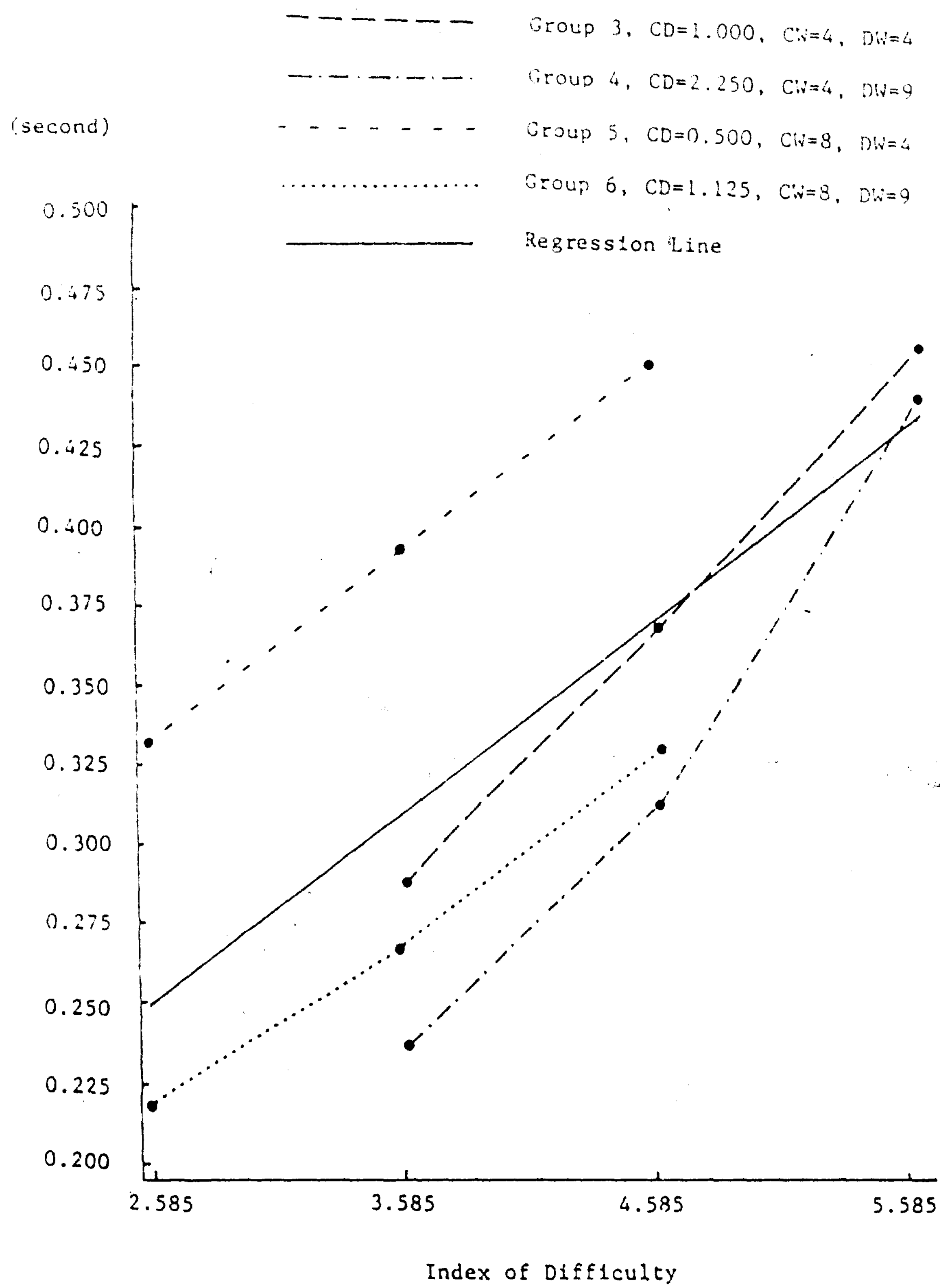

Figure 3: Mean GMTs Plotted Against IDs for Experimental Groups

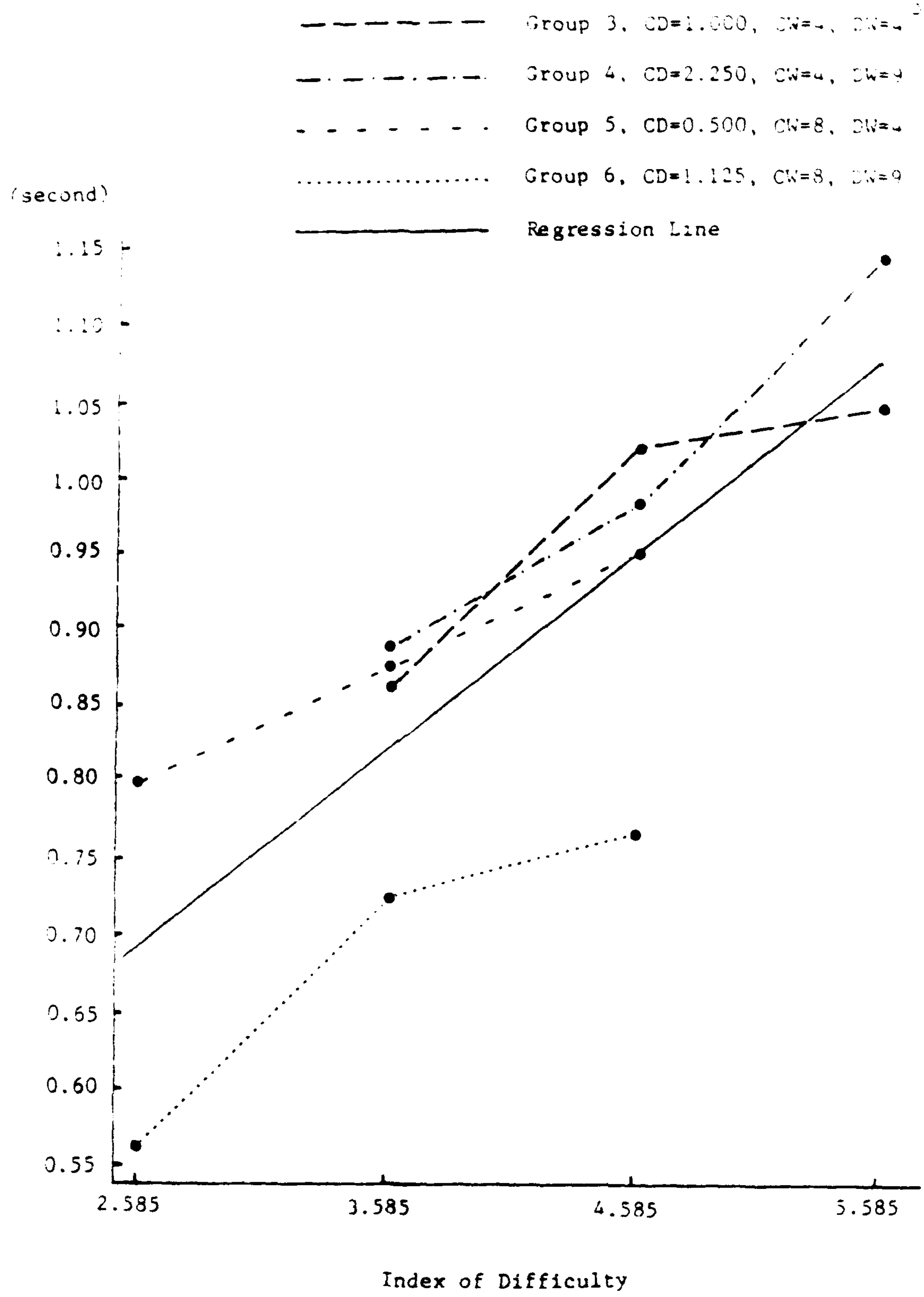

Figure 4: Mean FATs Plotted Against IDs for Experimental Groups

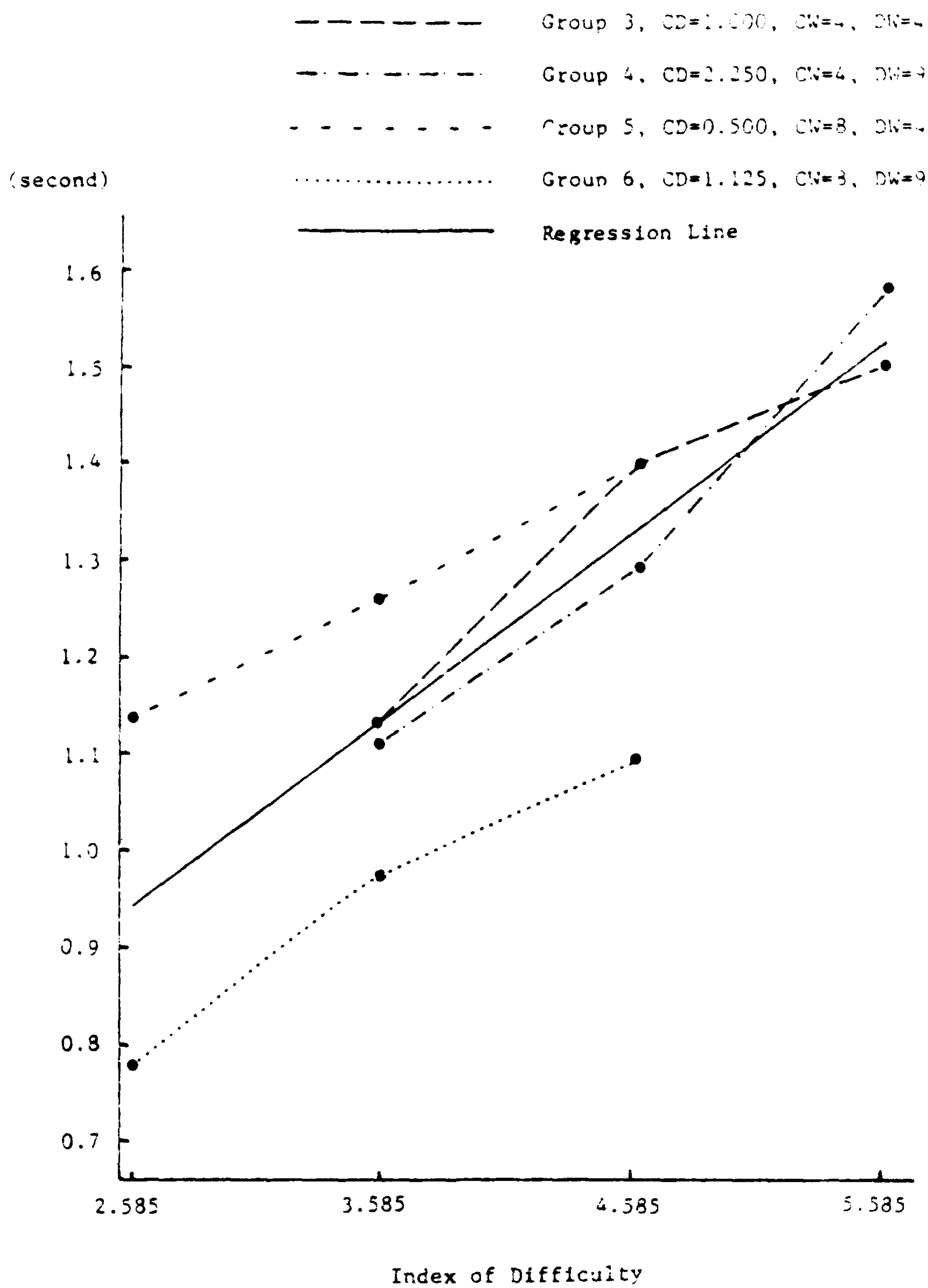

Figure 5: Mean MTs Plotted Against IDs for Experimental Groups

TABLE 10

Regression Equation Constants and Index of Performance

Dependent Variable	Group	Equation Constants (a)	(Prob < 0) (b)	IP
GMT	CTRL	-0.0824(0.1326)	0.0638(0.0038)	15.67
	EXPT	0.0975(0.2133)	0.0596(0.0067)	16.76
FAT	EXPT	0.3466(0.0159)	0.1319(0.0009)	7.58
MT	CTRL	0.0805(0.3617)	0.0685(0.0234)	14.60
	EXPT	0.4418(0.0208)	0.1915(0.0006)	5.22

response to minimize the response magnitudes and, consequently, to reduce the movement time and response errors. CW is another major factor which affected the performance. In addition, CW might interact with all other variables. These interactions usually mean that changing CW could make some insignificant variables become critical. For example, the CW by AMP interaction effect indicated that AMP variable might become more important under smaller CWs than under larger CWs; the CW by DW interaction effect indicated that the DW effect might be more prominent in the wide CW (i.e., CW=8) than the narrow CW (i.e., CW=4) conditions. In experimental groups, DW was also found to be an important factor that could affect the overall movement time and response accuracy. One unexpected finding was that GMT was found to be affected by SE, AMP, and CW*AMP effects, while FAT was affected by CW, AMP, and CW*DW effects. This was not correctly stated in the hypothesis which predicted DW would affect FAT, while CW would affect both GMT and FAT.

Finally, the SE effect and its interaction with CW and DW indicated that the learning effect could be significant even with such a relatively simple task, and CW and DW could have more effect on motor performance when an unfamiliar task was encountered. Therefore, the selection of appropriate control target widths and display target widths may become more important when novice operators are involved.

The Effect of Control-Display Gain

In the experimental groups, each group had a unique control target width and display target width combination which resulted in a unique control-display gain (C/D gain). Since the effect of C/D gain was confounded with the effects of CW and DW, the significant differences found among groups could be the result of differences in CWs, DWs, or C/D gains. Buck (1981) concluded that the significant differences found among groups in his study were due to CW and DW effects, but not the C/D gain effect. His conclusion seems arbitrary and unconvincing in the absence of supporting evidence. One way of arguing the effect of C/D gain is to prove that the numeric value of C/D gain has no systematic effect on motor performance. Figure 6 and Figure 7 demonstrate that smaller gains with larger CWs will be preferred when DWs are held constant. In contrast, larger gains with larger DWs will be preferred when CWs are held constant. The above arguments can be further supported when examining a recent study which employed a similar experimental task (Arnaut & Greenstein, 1985), although the authors of this study claimed the existance of a C/D gain

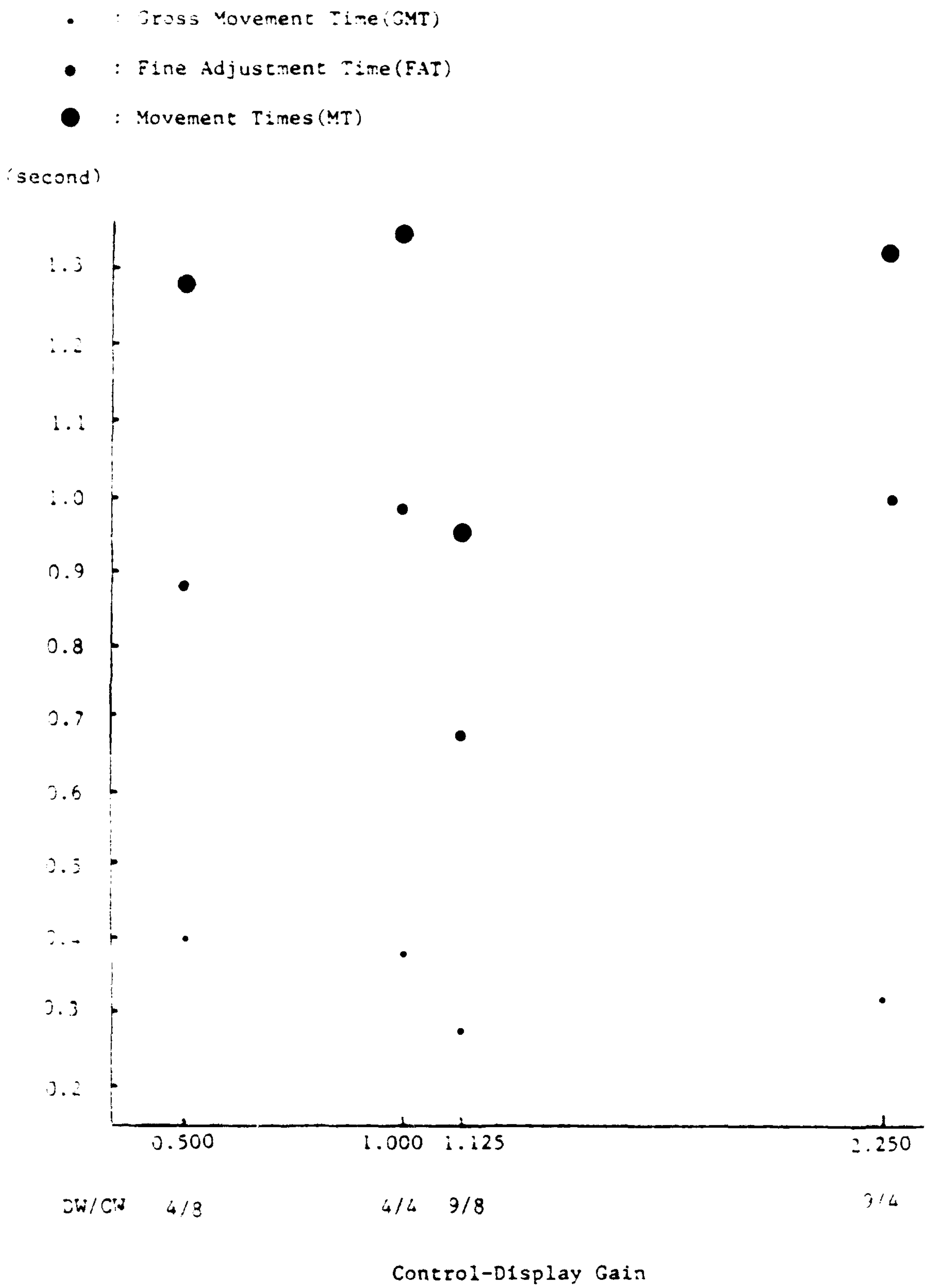

Figure 6: Mean GMTs, FATs, MTs Plotted Against CD Gains

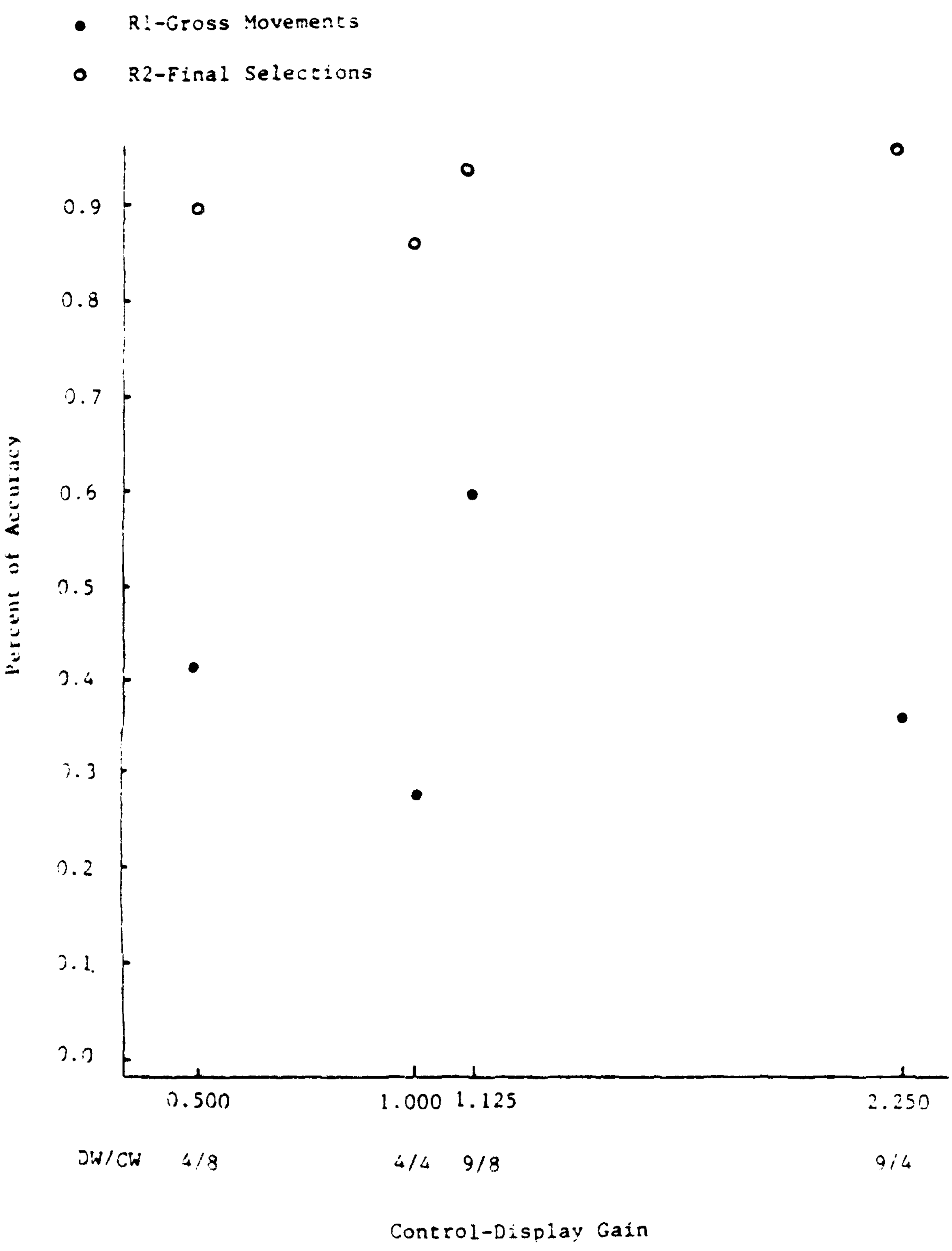

Figure 7: Mean R1s, R2s Plotted Against CD Gains

effect. In their study, larger gains were produced by decreasing CWs and keeping DWs constant. It can be expected that smaller C/D gains with larger CWs will be associated with better performance. In general, their data conformed to the above expectation. A sample of their data is shown in Table 11 and the arguments against C/D gain mentioned before can again be applied to Figure 8. Based upon the above arguments, one can hardly say which C/D gain is superior to others without knowing the values of CW and DW. Thus, finding an optimum C/D gain which has an effect independent of the effects of CW and DW is very doubtful.

For those C/D gain advocates who also believe in Fitts' Law and Fitts' Index of Performance (IP), Table 12 shows a little hope. It can be assumed that IP, which might be more independent of CW and DW effects, could be used as a criterion for evaluating the "true effect" of C/D gain. When considering the values of IP (bits/sec) computed from the regression line of each experimental group, Table 12 indicates that the smaller the C/D gains the larger the IP values. However, the validity of these measures is really hard to justify because only three data points were used to generate each regression line. More extensive studies are required in order to obtain conclusive proof of the existance of a C/D gain effect.

TABLE 11

Mean Rates of Target Selection for Absolute Mode

(From Arnaut & Greenstein, 1985)

Display Resolution	Gain 0.875	1.000	1.500	2.000	2.500
	targets/second(control target width)				
Low (3)	.51(3.43)	.53(3.00)	.52(2.00)	.47(1.50)	.45(1.20)
Med (2)	.48(2.29)	.47(2.00)	.47(1.33)	.43(1.00)	.40(0.80)
High(1)	.36(1.14)	.37(1.00)	.34(0.66)	.32(0.50)	.29(0.40)

Note:
The numbers in the parentheses are units for control target widths or display target widths.
One unit equals 8.1 mm.

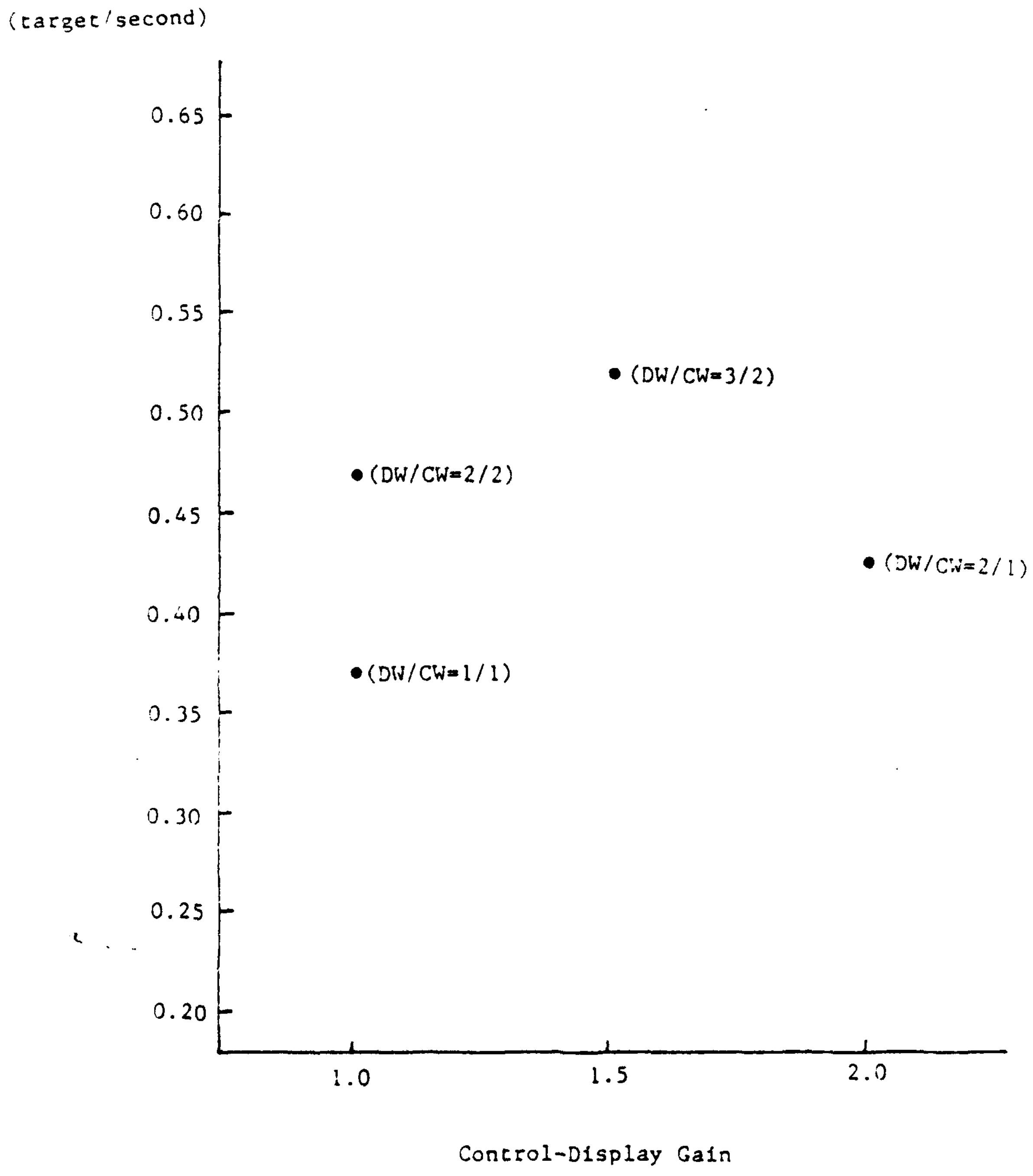

Figure 8: A Plot of Mean Rates of Target Selection from Table 11

TABLE 12

Index of Performance (IP) of Each Experimental Group

(bits/second)

C/D Gain	DW/CW	Group	GMT	FAT	MT
0.500	4/8	5	17.46	12.77	7.38
1.000	4/4	3	11.86	10.66	5.62
1.125	9/8	6	17.19	9.43	6.09
2.250	9/4	4	9.98	7.60	4.31

SUMMARY AND RECOMMENDATIONS

The digitizer-microcomputer-CRT configuration employed in this study provided a rigorous experimental paradigm for the study of the significance of C/D gain and the validation of Fitts' Law. The hypothesis of response normality could be easily tested within such a configuration. In fact, the above hypothesis could not be rejected in the study. However, the corrected ID values computed from effective control target widths and average movement amplitudes did not provide a better fit to the movement time data than the uncorrected ID values did. This introduces some doubt to the information-theoretic foundation of Fitts' Law.

Since the responses around the target areas were normally distributed, the standard deviations of the response distributions could be used to estimate the error rates of gross movements and final selections for a given control target width. Additionally, the effective control target widths (WE1 & WE2) computed from the standard deviations of the distributions of gross movements and final selections might have practical usefulness in helping interface designers specify the active control target areas and the inter-target displacements (or the "deadspace" around an active target area). WE2 indicates that about 96 percent of the final selections should fall inside of this area; so it can be used to specify the active target area. If a control target width is substantially larger than WE2, it indicates that a lot of useful space may be wasted given such large control target width. If a control target width is much smaller than WE2, it indicates that a task associated with such small control target width may be potentially difficult. WE1 indicates that about 96 percent of the gross movements should fall inside of this area; thus the difference between WE1 and WE2 could be used to specify the amount of space needed to separate the targets. This helps the specification of inter-target displacements or the "deadspace" around an active control target area.

Although Fitts' Law was not the most appropriate model of movement times for control groups or experimental groups in the study, its simplicity and capability of providing a relatively good fit to movement time data for control groups and the experimental group with a unique C/D gain should deserve more attention than other variables such as C/D gain. It has been demonstrated that the numeric value of C/D gain did not have a systematic effect on human motor performance. Instead, the effect was probably the combination of CW and DW effects. Since the specification of a particular C/D gain can actually influence the physical configuration of both control and display devices, this places a burden on the control-display interface designer. The finding of no systematic effect of C/D gain on motor performance might free the interface designers from the physical constraints on control and display devices imposed by the unnecessary C/D gain specification. It has also been indicated that AMP, DW, CW, and interactions between CW and other variables are all important factors that could affect motor performance. Thus, organizing responses in the vicinity of each other, arranging responses in a proper order, and selecting the appropriate control and target widths are all important design considerations.

In the study, subjects performed the same tasks in control groups or experimental groups, but the substantial differences in response speed, accuracy, and the size of effective control target widths indicated the importance of direct visual feedback of control movements. Thus, even with a simple task, providing direct visual cuing on the control device such as target labelling could reduce the response time and errors substantially.

Finally, the present study included only 2 levels of control and display target width, 3 levels of movement amplitude, and 4 different C/D gains. The experimental task was a simple target positioning task with static targets and with ID values ranging from 2.585 to 5.585. Thus, the results of the study may be limited in their applicability to other tasks or similar tasks with different ranges on each variable. More extensive examination of the above variables may be required in order to obtain a more general conclusion.

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Appendix A

REGRESSION EQUATIONS AND PREDICTED SAMPLE DATA

An "All Possible Regressions" method was used to select the predictors of each regression equation from a pool of variables which showed the significant effects on the variable being predicted. The following regression equations were used to predict the effective control target widths and movement times. A computer program and a list of predicted data were also included.

Predicted Variable	Regression Equation	NI	NE	R^2	Cp
WEC1	1.520553 + 0.547697*CW + 0.002189*CWAMP	2	4	0.98	11.59
WEC2	1.196767 + 0.581104*CW + 0.001920*CWAMP	2	4	0.98	4.26
WEE1	14.745246 - 0.452948*DW + 0.290248*AMP	2	7	0.85	15.33
WEE2	8.926248 - 0.368546*DW + 0.009930*CWAMP	2	4	0.64	2.92
GMT	0.331114 - 0.015990*DW + 0.002037*AMP	2	4	0.88	4.16
FAT	0.732676 + 0.102430*ID - 0.026987*CW - 0.015980*DW	3	6	0.84	27.47
MTC	0.296407 + 0.046187*ID - 0.020424*CW	2	3	0.98	2.38

Note:

- WEC1 : WE1 of control groups.
- WEC2 : WE2 of control groups.
- WEE1 : WE1 of experimental groups.
- WEE2 : WE2 of experimental groups.
- GMT : gross movement time of experimental groups.
- FAT : fine adjustment time of experimental groups.
- MTC : movement time of control groups.
- NI : number of predictors included in the equation.
- NE : number of predictors examined.

```
REGTEST : PROC OPTIONS (MAIN);
/**********************************************************
 *  ** WRITTEN BY:                      Andy Parng         *
 *  ** DATE WRITTEN:                    November 18, 1985  *
 *  ** PROGRAM SUMMARY:                                    *
 *  This program was written to use the regression        *
 *  equations derived from the experiment to predict      *
 *  the effective target widths of both gross movements   *
 *  and final selections (WEE1, WEE2, WEC1, & WEC2),       *
 *  gross movement time (GMT), fine adjustment time (FAT)*
 *  and movement time (MTE) for experimental groups, and *
 *  movement time(MTC) for control groups.  The minimum   *
 *  FAT and GMT (or MTC) were arbitrarily set to 0.030    *
 *  second and ID/30 second respectively.  GMT, MTC, and *
 *  FAT were replaced by the minimum values if they were *
 *  smaller than those minimum values.                    *
 **********************************************************/

 DECLARE
   COUNT          FIXED BINARY(15) INIT(0),
   GMT_COUNT      FIXED BINARY(15) INIT(0),
   FAT_COUNT      FIXED BINARY(15) INIT(0),
   MTC_COUNT      FIXED BINARY(15) INIT(0),
   PAGE_NUM       FIXED BINARY(15) INIT(1),
   GMT_FLAG       BIT(1) INIT('0'B),
   FAT_FLAG       BIT(1) INIT('0'B),
   MTC_FLAG       BIT(1) INIT('0'B),
   CW             FIXED BINARY,
   DW             FIXED BINARY,
   AMP            FIXED BINARY,
   CWAMP          FIXED BINARY,
   GAIN           FLOAT DEC(6),
   ID             FLOAT DEC(6),
   GMT            FLOAT DEC(6),
   MIN_GMT        FLOAT DEC(6),
   MIN_FAT        FLOAT DEC(6),
   FAT            FLOAT DEC(6),
   MTC            FLOAT DEC(6),
   MTE            FLOAT DEC(6),
   WEE1           FLOAT DEC(6),
   WEE2           FLOAT DEC(6),
   WEC1           FLOAT DEC(6),
   WEC2           FLOAT DEC(6),
   LOG2           BUILTIN,
   FLOAT          BUILTIN,
   SYSPRINT       FILE STREAM OUTPUT PRINT;

   ON ENDPAGE(SYSPRINT)
   BEGIN;
     IF PAGE_NUM ¢= 1 THEN PUT PAGE;
     PUT SKIP(4);
     PUT EDIT (PAGE_NUM) (COL(69),F(2));
     PUT SKIP(2) EDIT
       ('CW','DW','AMP','GAIN','ID','WEC1','WEC2','WEE1',
```

```
        'WEE2','GMT','FAT','MTE','MTC')
       (COL(5),A,COL(8),A,COL(11),A,
        COL(15),A,COL(21),A,COL(26),A,
        COL(32),A,COL(38),A,
        COL(44),A,COL(51),A,COL(58),A,
        COL(65),A,COL(72),A);
     PUT SKIP(0) EDIT
       ('__','__','___','_____','_____','_____','_____',
        '_____','_____','______','______','______','______')
       (COL(5),A,COL(8),A,COL(11),A,
        COL(15),A,COL(20),A,COL(26),A,
        COL(32),A,COL(38),A,
        COL(44),A,COL(50),A,COL(57),A,
        COL(64),A,COL(71),A);
     PUT SKIP(2);
     PAGE_NUM = PAGE_NUM + 1;
   END;

 SIGNAL ENDPAGE(SYSPRINT);

 DO CW = 2 TO 20 BY 3;
   DO DW = 2 TO 29 BY 3;
     GAIN = FLOAT(DW,6) / CW;
     IF (GAIN >= 0.5) & (GAIN <=2.25) THEN
       DO;
         DO AMP = 25 TO 250 BY 25;
           ID = LOG2(2*FLOAT(AMP,6)/CW);
           IF (ID >= 2) & (ID <= 10) THEN
             DO;
               CWAMP = CW * AMP;
               WEC1 = 1.520553 + 0.547697*CW + 0.002189*CWAMP;
               WEC2 = 1.196767 + 0.581104*CW + 0.001920*CWAMP;
               WEE1 =14.745246 - 0.452948*DW + 0.290248*AMP;
               WEE2 = 8.926248 - 0.368546*DW + 0.009930*CWAMP;
               GMT  = 0.331114 - 0.015990*DW + 0.002037*AMP;
               FAT  = 0.732676 + 0.102430*ID - 0.026987*CW -
                      0.015980*DW;
               MTC  = 0.296407 + 0.046187*ID - 0.020424*CW;
               MIN_GMT = ID / 30;
               MIN_FAT = FLOAT(0.030,6);
               IF GMT < MIN_GMT THEN DO;
                 GMT = MIN_GMT;
                 GMT_FLAG = '1'B;
               END;
                 IF FAT < MIN_FAT THEN DO;
                 FAT = MIN_FAT;
                 FAT_FLAG = '1'B;
               END;
               IF MTC < MIN_GMT THEN DO;
                 MTC = MIN_GMT;
                 MTC_FLAG = '1'B;
               END;
               MTE = GMT + FAT;
               PUT EDIT (CW,DW,AMP,GAIN,ID,WEC1,WEC2,
```

```
                    WEE1,WEE2,GMT,FAT,MTE,MTC)
                (COL(5),F(2),COL(8),F(2),COL(11),
                 F(3),COL(15),F(4,2),COL(20),F(4,2),COL(25),
                 F(5,2),COL(31),F(5,2),COL(37),F(5,2),
                 COL(43),F(5,2),COL(50),F(5,3),COL(57),
                 F(5,3),COL(64),F(5,3),COL(71),F(5,3));
              COUNT = COUNT + 1;
              IF GMT_FLAG = '1'B THEN DO;
                PUT SKIP(0) EDIT('*','*')(COL(49),A,COL(63),A
                GMT_COUNT = GMT_COUNT + 1;
              END;
              IF FAT_FLAG = '1'B THEN DO;
                PUT SKIP(0) EDIT('*','*')(COL(56),A,COL(63),A
                FAT_COUNT = FAT_COUNT + 1;
              END;
              IF MTC_FLAG = '1'B THEN DO;
                PUT SKIP(0) EDIT('*') (COL(70),A);
                MTC_COUNT = MTC_COUNT + 1;
              END;
              PUT SKIP(1);
              GMT_FLAG = '0'B;
              FAT_FLAG = '0'B;
              MTC_FLAG = '0'B;
            END;
        END;
      END;
  END;
END;
PUT SKIP(2)EDIT
  ('Number of Substitutions of GMT with MIN_GMT:',
   GMT_COUNT)
  (COL(5),A,COL(55),F(4));
PUT SKIP(2)EDIT
  ('Number of Substitutions of FAT with MIN_FAT:',
   FAT_COUNT)
  (COL(5),A,COL(55),F(4));
PUT SKIP(2)EDIT
  ('Number of Substitutions of MTC with MIN_GMT:',
   MTC_COUNT)
  (COL(5),A,COL(55),F(4));
PUT SKIP(2)EDIT('Total Conditions Predicted:',COUNT)
  (COL(5),A,COL(55),F(4)):
END REGTEST;
```

CW	DW	AMP	GAIN	ID	WEC1	WEC2	WEE1	WEE2	GBT	FAT	STE	MTC
2	2	25	1.00	4.64	2.73	2.45	21.10	8.69	0.350	1.122	1.472	0.470
2	2	50	1.00	5.64	2.83	2.55	28.35	9.18	0.401	1.225	1.626	0.516
2	2	75	1.00	6.23	2.94	2.65	35.61	9.68	0.452	1.285	1.737	0.543
2	2	100	1.00	6.64	3.05	2.74	42.86	10.18	0.503	1.327	1.830	0.562
2	2	125	1.00	6.97	3.16	2.84	50.12	10.67	0.554	1.360	1.914	0.577
2	2	150	1.00	7.23	3.27	2.93	57.38	11.17	0.605	1.387	1.992	0.589
2	2	175	1.00	7.45	3.38	3.03	64.63	11.66	0.655	1.410	2.065	0.600
2	2	200	1.00	7.64	3.49	3.13	71.89	12.16	0.706	1.430	2.136	0.609
2	2	225	1.00	7.81	3.60	3.22	79.15	12.66	0.757	1.447	2.204	0.616
2	2	250	1.00	7.97	3.71	3.32	86.40	13.15	0.808	1.463	2.271	0.623
5	5	25	1.00	3.32	4.53	4.34	19.74	8.32	0.302	0.858	1.160	0.348
5	5	50	1.00	4.32	4.81	4.58	26.99	9.57	0.353	0.961	1.314	0.394
5	5	75	1.00	4.91	5.08	4.82	34.25	10.81	0.404	1.020	1.424	0.421
5	5	100	1.00	5.32	5.35	5.06	41.51	12.05	0.455	1.063	1.518	0.440
5	5	125	1.00	5.64	5.63	5.30	48.76	13.29	0.506	1.096	1.602	0.455
5	5	150	1.00	5.91	5.90	5.54	56.02	14.53	0.557	1.123	1.679	0.467
5	5	175	1.00	6.13	6.17	5.78	63.27	15.77	0.607	1.146	1.753	0.477
5	5	200	1.00	6.32	6.45	6.02	70.53	17.01	0.658	1.165	1.824	0.486
5	5	225	1.00	6.49	6.72	6.26	77.79	18.25	0.709	1.183	1.892	0.494
5	5	250	1.00	6.64	6.99	6.50	85.04	19.50	0.760	1.198	1.959	0.501
5	8	25	1.60	3.32	4.53	4.34	18.38	7.22	0.254	0.810	1.064	0.348
5	8	50	1.60	4.32	4.81	4.58	25.63	8.46	0.305	0.913	1.218	0.394
5	8	75	1.60	4.91	5.08	4.82	32.89	9.70	0.356	0.973	1.328	0.421
5	8	100	1.60	5.32	5.35	5.06	40.15	10.94	0.407	1.015	1.422	0.440
5	8	125	1.60	5.64	5.63	5.30	47.40	12.18	0.458	1.048	1.506	0.455
5	8	150	1.60	5.91	5.90	5.54	54.66	13.43	0.509	1.075	1.584	0.467
5	8	175	1.60	6.13	6.17	5.78	61.92	14.67	0.560	1.098	1.657	0.477
5	8	200	1.60	6.32	6.45	6.02	69.17	15.91	0.610	1.117	1.728	0.486
5	8	225	1.60	6.49	6.72	6.26	76.43	17.15	0.661	1.135	1.796	0.494
5	8	250	1.60	6.64	6.99	6.50	83.68	18.39	0.712	1.150	1.863	0.501
5	11	25	2.20	3.32	4.53	4.34	17.02	6.11	0.206	0.762	0.968	0.348
5	11	50	2.20	4.32	4.81	4.58	24.28	7.35	0.257	0.865	1.122	0.394
5	11	75	2.20	4.91	5.08	4.82	31.53	8.60	0.308	0.925	1.233	0.421
5	11	100	2.20	5.32	5.35	5.06	38.79	9.84	0.359	0.967	1.326	0.440
5	11	125	2.20	5.64	5.63	5.30	46.04	11.08	0.410	1.000	1.410	0.455
5	11	150	2.20	5.91	5.90	5.54	53.30	12.32	0.461	1.027	1.488	0.467
5	11	175	2.20	6.13	6.17	5.78	60.56	13.56	0.512	1.050	1.561	0.477
5	11	200	2.20	6.32	6.45	6.02	67.81	14.80	0.562	1.070	1.632	0.486
5	11	225	2.20	6.49	6.72	6.26	75.07	16.04	0.613	1.087	1.700	0.494
5	11	250	2.20	6.64	6.99	6.50	82.32	17.28	0.664	1.102	1.767	0.501
8	5	25	0.63	2.64	6.34	6.23	19.74	9.07	0.302	0.708	1.010	0.255
8	5	50	0.63	3.64	6.78	6.61	25.99	11.06	0.353	0.810	1.163	0.301
8	5	75	0.63	4.23	7.22	7.00	34.25	13.04	0.404	0.870	1.274	0.328
8	5	100	0.63	4.64	7.65	7.38	41.51	15.03	0.455	0.913	1.367	0.348
8	5	125	0.63	4.97	8.09	7.77	48.76	17.01	0.506	0.946	1.451	0.362
8	5	150	0.63	5.23	8.53	8.15	56.02	19.00	0.557	0.972	1.529	0.375
8	5	175	0.63	5.45	8.97	8.53	63.27	20.99	0.607	0.995	1.603	0.385
8	5	200	0.63	5.64	9.40	8.92	70.53	22.97	0.658	1.015	1.673	0.394
8	5	225	0.63	5.81	9.84	9.30	77.79	24.96	0.709	1.032	1.742	0.402
8	5	250	0.63	5.97	10.28	9.69	85.04	26.94	0.760	1.048	1.808	0.409
8	8	25	1.00	2.64	6.34	6.23	18.38	7.96	0.254	0.660	0.914	0.255
8	8	50	1.00	3.64	6.78	6.61	25.63	9.95	0.305	0.762	1.067	0.301
8	8	75	1.00	4.23	7.22	7.00	32.89	11.94	0.356	0.822	1.178	0.328
8	8	100	1.00	4.64	7.65	7.38	40.15	13.92	0.407	0.865	1.271	0.348
8	8	125	1.00	4.97	8.09	7.77	47.40	15.91	0.458	0.898	1.355	0.362

CW	DW	AMP	GAIN	ID	WFC1	WFC2	WFE1	WFE2	GMT	FAT	MTE	MTC
8	8	150	1.00	5.23	8.53	8.15	54.66	17.89	0.509	0.925	1.433	0.375
8	8	175	1.00	5.45	8.97	8.53	61.92	19.88	0.560	0.947	1.507	0.385
8	8	200	1.00	5.64	9.40	8.92	69.17	21.87	0.610	0.967	1.577	0.394
8	8	225	1.00	5.81	9.84	9.30	76.43	23.85	0.661	0.984	1.646	0.402
8	8	250	1.00	5.97	10.28	9.69	83.68	25.84	0.712	1.000	1.712	0.409
8	11	25	1.38	2.64	6.34	6.23	17.02	6.86	0.206	0.612	0.818	0.255
8	11	50	1.38	3.64	6.78	6.61	24.28	8.84	0.257	0.714	0.971	0.301
8	11	75	1.38	4.23	7.22	7.00	31.53	10.83	0.308	0.774	1.082	0.328
8	11	100	1.38	4.64	7.65	7.38	38.79	12.82	0.359	0.817	1.176	0.348
8	11	125	1.38	4.97	8.09	7.77	46.04	14.80	0.410	0.850	1.259	0.362
8	11	150	1.38	5.23	8.53	8.15	53.30	16.79	0.461	0.877	1.337	0.375
8	11	175	1.38	5.45	8.97	8.53	60.56	18.77	0.512	0.899	1.411	0.385
8	11	200	1.38	5.64	9.40	8.92	67.81	20.76	0.562	0.919	1.482	0.394
8	11	225	1.38	5.81	9.84	9.30	75.07	22.75	0.613	0.937	1.550	0.402
8	11	250	1.38	5.97	10.28	9.69	82.32	24.73	0.664	0.952	1.616	0.409
8	14	25	1.75	2.64	6.34	6.23	15.66	5.75	0.158	0.564	0.722	0.255
8	14	50	1.75	3.64	6.78	6.61	22.92	7.74	0.209	0.666	0.875	0.301
8	14	75	1.75	4.23	7.22	7.00	30.17	9.72	0.260	0.726	0.986	0.328
8	14	100	1.75	4.64	7.65	7.38	37.43	11.71	0.311	0.769	1.080	0.348
8	14	125	1.75	4.97	8.09	7.77	44.68	13.70	0.362	0.802	1.163	0.362
8	14	150	1.75	5.23	8.53	8.15	51.94	15.68	0.413	0.829	1.241	0.375
8	14	175	1.75	5.45	8.97	8.53	59.20	17.67	0.464	0.851	1.315	0.385
8	14	200	1.75	5.64	9.40	8.92	66.45	19.65	0.514	0.871	1.386	0.394
8	14	225	1.75	5.81	9.84	9.30	73.71	21.64	0.565	0.889	1.454	0.402
8	14	250	1.75	5.97	10.28	9.69	80.97	23.63	0.616	0.904	1.520	0.409
8	17	25	2.13	2.64	6.34	6.23	14.30	4.65	0.110	0.516	0.626	0.255
8	17	50	2.13	3.64	6.78	6.61	21.56	6.63	0.161	0.618	0.779	0.301
8	17	75	2.13	4.23	7.22	7.00	28.81	8.62	0.212	0.678	0.890	0.328
8	17	100	2.13	4.64	7.65	7.38	36.07	10.60	0.263	0.721	0.984	0.348
8	17	125	2.13	4.97	8.09	7.77	43.33	12.59	0.314	0.754	1.068	0.362
8	17	150	2.13	5.23	8.53	8.15	50.58	14.58	0.365	0.781	1.145	0.375
8	17	175	2.13	5.45	8.97	8.53	57.84	16.56	0.416	0.803	1.219	0.385
8	17	200	2.13	5.64	9.40	8.92	65.09	18.55	0.467	0.823	1.290	0.394
8	17	225	2.13	5.81	9.84	9.30	72.35	20.53	0.517	0.841	1.358	0.402
8	17	250	2.13	5.97	10.28	9.69	79.61	22.52	0.568	0.856	1.425	0.409
11	8	25	0.73	2.18	8.15	8.12	18.38	8.71	0.254	0.532	0.786	0.173
11	8	50	0.73	3.18	8.75	8.64	25.63	11.44	0.305	0.634	0.939	0.219
11	8	75	0.73	3.77	9.35	9.17	32.89	14.17	0.356	0.694	1.050	0.246
11	8	100	0.73	4.18	9.95	9.70	40.15	16.90	0.407	0.737	1.143	0.265
11	8	125	0.73	4.51	10.55	10.23	47.40	19.63	0.458	0.770	1.227	0.280
11	8	150	0.73	4.77	11.16	10.76	54.66	22.36	0.509	0.797	1.305	0.292
11	8	175	0.73	4.99	11.76	11.28	61.92	25.09	0.560	0.819	1.379	0.302
11	8	200	0.73	5.18	12.36	11.81	69.17	27.82	0.610	0.839	1.449	0.311
11	8	225	0.73	5.35	12.96	12.34	76.43	30.55	0.661	0.856	1.518	0.319
11	8	250	0.73	5.51	13.56	12.87	83.68	33.28	0.712	0.872	1.584	0.326
11	11	25	1.00	2.18	8.15	8.12	17.02	7.60	0.206	0.484	0.690	0.173
11	11	50	1.00	3.18	8.75	8.64	24.28	10.33	0.257	0.586	0.843	0.219
11	11	75	1.00	3.77	9.35	9.17	31.53	13.06	0.308	0.646	0.954	0.246
11	11	100	1.00	4.18	9.95	9.70	38.79	15.79	0.359	0.689	1.048	0.265
11	11	125	1.00	4.51	10.55	10.23	46.04	18.53	0.410	0.722	1.131	0.280
11	11	150	1.00	4.77	11.16	10.76	53.30	21.26	0.461	0.749	1.209	0.292
11	11	175	1.00	4.99	11.76	11.28	60.56	23.99	0.512	0.771	1.283	0.302
11	11	200	1.00	5.18	12.36	11.81	67.81	26.72	0.562	0.791	1.354	0.311
11	11	225	1.00	5.35	12.96	12.34	75.07	29.45	0.613	0.808	1.422	0.319

CW	DW	AMP	GAIN	ID	WEC1	WEC2	WEE1	WEE2	GMT	FAT	STE	STC
11	11	250	1.00	5.51	13.56	12.87	82.32	32.18	0.664	0.824	1.488	0.326
11	14	25	1.27	2.18	8.15	8.12	15.66	6.50	0.158	0.436	0.594	0.173
11	14	50	1.27	3.18	8.75	8.64	22.92	9.23	0.209	0.538	0.747	0.219
11	14	75	1.27	3.77	9.35	9.17	30.17	11.96	0.260	0.598	0.858	0.246
11	14	100	1.27	4.18	9.95	9.70	37.43	14.69	0.311	0.641	0.952	0.265
11	14	125	1.27	4.51	10.55	10.23	44.68	17.42	0.362	0.674	1.035	0.280
11	14	150	1.27	4.77	11.16	10.76	51.94	20.15	0.413	0.701	1.113	0.292
11	14	175	1.27	4.99	11.76	11.28	59.20	22.88	0.464	0.723	1.187	0.302
11	14	200	1.27	5.18	12.36	11.81	66.45	25.61	0.514	0.743	1.258	0.311
11	14	225	1.27	5.35	12.96	12.34	73.71	28.34	0.565	0.761	1.326	0.319
11	14	250	1.27	5.51	13.56	12.87	80.97	31.07	0.616	0.776	1.392	0.326
11	17	25	1.55	2.18	8.15	8.12	14.30	5.39	0.110	0.388	0.498	0.173
11	17	50	1.55	3.18	8.75	8.64	21.56	8.12	0.161	0.490	0.651	0.219
11	17	75	1.55	3.77	9.35	9.17	28.81	10.85	0.212	0.550	0.762	0.246
11	17	100	1.55	4.18	9.95	9.70	36.07	13.58	0.263	0.593	0.856	0.265
11	17	125	1.55	4.51	10.55	10.23	43.33	16.31	0.314	0.626	0.940	0.280
11	17	150	1.55	4.77	11.16	10.76	50.58	19.04	0.365	0.653	1.017	0.292
11	17	175	1.55	4.99	11.76	11.28	57.84	21.78	0.416	0.675	1.091	0.302
11	17	200	1.55	5.18	12.36	11.81	65.09	24.51	0.467	0.695	1.162	0.311
11	17	225	1.55	5.35	12.96	12.34	72.35	27.24	0.517	0.713	1.230	0.319
11	17	250	1.55	5.51	13.56	12.87	79.61	29.97	0.568	0.728	1.297	0.326
11	20	25	1.82	2.18	8.15	8.12	12.94	4.29	*0.073	0.340	*0.413	0.173
11	20	50	1.82	3.18	8.75	8.64	20.20	7.02	0.113	0.442	0.556	0.219
11	20	75	1.82	3.77	9.35	9.17	27.45	9.75	0.164	0.502	0.666	0.246
11	20	100	1.82	4.18	9.95	9.70	34.71	12.48	0.215	0.545	0.760	0.265
11	20	125	1.82	4.51	10.55	10.23	41.97	15.21	0.266	0.578	0.844	0.280
11	20	150	1.82	4.77	11.16	10.76	49.22	17.94	0.317	0.605	0.922	0.292
11	20	175	1.82	4.99	11.76	11.28	56.48	20.67	0.368	0.628	0.995	0.302
11	20	200	1.82	5.18	12.36	11.81	63.74	23.40	0.419	0.647	1.066	0.311
11	20	225	1.82	5.35	12.96	12.34	70.99	26.13	0.469	0.665	1.134	0.319
11	20	250	1.82	5.51	13.56	12.87	78.25	28.86	0.520	0.680	1.201	0.326
11	23	25	2.09	2.18	8.15	8.12	11.58	3.18	*0.073	0.292	*0.365	0.173
11	23	50	2.09	3.18	8.75	8.64	18.84	5.91	*0.106	0.394	*0.501	0.219
11	23	75	2.09	3.77	9.35	9.17	26.10	8.64	*0.126	0.454	*0.580	0.246
11	23	100	2.09	4.18	9.95	9.70	33.35	11.37	0.167	0.497	0.664	0.265
11	23	125	2.09	4.51	10.55	10.23	40.61	14.10	0.218	0.530	0.748	0.280
11	23	150	2.09	4.77	11.16	10.76	47.86	16.83	0.269	0.557	0.826	0.292
11	23	175	2.09	4.99	11.76	11.28	55.12	19.56	0.320	0.580	0.899	0.302
11	23	200	2.09	5.18	12.36	11.81	62.38	22.29	0.371	0.599	0.970	0.311
11	23	225	2.09	5.35	12.96	12.34	69.63	25.03	0.421	0.617	1.038	0.319
11	23	250	2.09	5.51	13.56	12.87	76.89	27.76	0.472	0.632	1.105	0.326
14	8	50	0.57	2.84	10.72	10.68	25.63	12.93	0.305	0.518	0.823	0.141
14	8	75	0.57	3.42	11.49	11.35	32.89	16.40	0.356	0.577	0.933	0.168
14	8	100	0.57	3.84	12.25	12.02	40.15	19.88	0.407	0.620	1.027	0.188
14	8	125	0.57	4.16	13.02	12.69	47.40	23.35	0.458	0.653	1.111	0.203
14	8	150	0.57	4.42	13.78	13.36	54.66	26.83	0.509	0.680	1.189	0.215
14	8	175	0.57	4.64	14.55	14.04	61.92	30.31	0.560	0.703	1.262	0.225
14	8	200	0.57	4.84	15.32	14.71	69.17	33.78	0.610	0.722	1.333	0.234
14	8	225	0.57	5.01	16.08	15.38	76.43	37.26	0.661	0.740	1.401	0.242
14	8	250	0.57	5.16	16.85	16.05	83.68	40.73	0.712	0.755	1.468	0.249
14	11	50	0.79	2.84	10.72	10.68	24.28	11.82	0.257	0.470	0.727	0.141
14	11	75	0.79	3.42	11.49	11.35	31.53	15.30	0.308	0.530	0.837	0.168
14	11	100	0.79	3.84	12.25	12.02	38.79	18.77	0.359	0.572	0.931	0.188
14	11	125	0.79	4.16	13.02	12.69	46.04	22.25	0.410	0.605	1.015	0.203

CW	DW	AMP	GAIN	ID	WPC1	WPC2	WPP1	WPP2	GHT	FAT	STR	STC
14	11	150	0.79	4.42	13.78	13.36	53.30	25.72	0.461	0.632	1.093	0.215
14	11	175	0.79	4.64	14.55	14.04	60.56	29.20	0.512	0.655	1.166	0.225
14	11	200	0.79	4.84	15.32	14.71	67.81	32.68	0.562	0.674	1.237	0.234
14	11	225	0.79	5.01	16.08	15.38	75.07	36.15	0.613	0.692	1.305	0.242
14	11	250	0.79	5.16	16.85	16.05	82.32	39.63	0.664	0.707	1.372	0.249
14	14	50	1.00	2.84	10.72	10.68	22.92	10.72	0.209	0.422	0.631	0.141
14	14	75	1.00	3.42	11.49	11.35	30.17	14.19	0.260	0.482	0.742	0.168
14	14	100	1.00	3.84	12.25	12.02	37.43	17.67	0.311	0.524	0.835	0.188
14	14	125	1.00	4.16	13.02	12.69	44.68	21.14	0.362	0.557	0.919	0.203
14	14	150	1.00	4.42	13.78	13.36	51.94	24.62	0.413	0.584	0.997	0.215
14	14	175	1.00	4.64	14.55	14.04	59.20	28.09	0.464	0.607	1.070	0.225
14	14	200	1.00	4.84	15.32	14.71	66.45	31.57	0.514	0.627	1.141	0.234
14	14	225	1.00	5.01	16.08	15.38	73.71	35.05	0.565	0.644	1.209	0.242
14	14	250	1.00	5.16	16.85	16.05	80.97	38.52	0.616	0.660	1.276	0.249
14	17	50	1.21	2.84	10.72	10.68	21.56	9.61	0.161	0.374	0.535	0.141
14	17	75	1.21	3.42	11.49	11.35	28.31	13.09	0.212	0.434	0.646	0.168
14	17	100	1.21	3.84	12.25	12.02	36.07	16.56	0.263	0.476	0.739	0.188
14	17	125	1.21	4.16	13.02	12.69	43.33	20.04	0.314	0.509	0.823	0.203
14	17	150	1.21	4.42	13.78	13.36	50.58	23.51	0.365	0.536	0.901	0.215
14	17	175	1.21	4.64	14.55	14.04	57.84	26.99	0.416	0.559	0.974	0.225
14	17	200	1.21	4.84	15.32	14.71	65.09	30.46	0.467	0.579	1.045	0.234
14	17	225	1.21	5.01	16.08	15.38	72.35	33.94	0.517	0.596	1.113	0.242
14	17	250	1.21	5.16	16.85	16.05	79.61	37.41	0.568	0.612	1.180	0.249
14	20	50	1.43	2.84	10.72	10.68	20.20	8.51	0.113	0.326	0.439	0.141
14	20	75	1.43	3.42	11.49	11.35	27.45	11.98	0.164	0.386	0.550	0.168
14	20	100	1.43	3.84	12.25	12.02	34.71	15.46	0.215	0.428	0.643	0.188
14	20	125	1.43	4.16	13.02	12.69	41.97	18.93	0.266	0.461	0.727	0.203
14	20	150	1.43	4.42	13.78	13.36	49.22	22.41	0.317	0.488	0.805	0.215
14	20	175	1.43	4.64	14.55	14.04	56.48	25.88	0.368	0.511	0.879	0.225
14	20	200	1.43	4.84	15.32	14.71	63.74	29.36	0.419	0.531	0.949	0.234
14	20	225	1.43	5.01	16.08	15.38	70.99	32.83	0.469	0.548	1.018	0.242
14	20	250	1.43	5.16	16.85	16.05	78.25	36.31	0.520	0.564	1.084	0.249
14	23	50	1.64	2.84	10.72	10.68	18.84	7.40	*0.095	0.278	*0.372	0.141
14	23	75	1.64	3.42	11.49	11.35	26.10	10.88	0.116	0.338	0.454	0.168
14	23	100	1.64	3.84	12.25	12.02	33.35	14.35	0.167	0.380	0.547	0.188
14	23	125	1.64	4.16	13.02	12.69	40.61	17.83	0.218	0.413	0.631	0.203
14	23	150	1.64	4.42	13.78	13.36	47.86	21.30	0.269	0.440	0.709	0.215
14	23	175	1.64	4.64	14.55	14.04	55.12	24.78	0.320	0.463	0.783	0.225
14	23	200	1.64	4.84	15.32	14.71	62.38	28.25	0.371	0.483	0.853	0.234
14	23	225	1.64	5.01	16.08	15.38	69.63	31.73	0.421	0.500	0.922	0.242
14	23	250	1.64	5.16	16.85	16.05	76.89	35.20	0.472	0.516	0.988	0.249
14	26	50	1.86	2.84	10.72	10.68	17.48	6.29	*0.095	0.230	*0.324	0.141
14	26	75	1.86	3.42	11.49	11.35	24.74	9.77	*0.114	0.290	*0.404	0.168
14	26	100	1.86	3.84	12.25	12.02	31.99	13.25	*0.128	0.332	*0.460	0.188
14	26	125	1.86	4.16	13.02	12.69	39.25	16.72	0.170	0.365	0.535	0.203
14	26	150	1.86	4.42	13.78	13.36	46.51	20.20	0.221	0.392	0.613	0.215
14	26	175	1.86	4.64	14.55	14.04	53.76	23.67	0.272	0.415	0.687	0.225
14	26	200	1.86	4.84	15.32	14.71	61.02	27.15	0.323	0.435	0.757	0.234
14	26	225	1.86	5.01	16.08	15.38	68.27	30.62	0.374	0.452	0.826	0.242
14	26	250	1.86	5.16	16.85	16.05	75.53	34.10	0.424	0.468	0.892	0.249
14	29	50	2.07	2.84	10.72	10.68	16.12	5.19	*0.095	0.182	*0.277	0.141
14	29	75	2.07	3.42	11.49	11.35	23.38	8.66	*0.114	0.242	*0.356	0.168
14	29	100	2.07	3.84	12.25	12.02	30.63	12.14	*0.128	0.284	*0.412	0.188
14	29	125	2.07	4.16	13.02	12.69	37.89	15.62	*0.139	0.317	*0.456	0.203

CH	DB	AMP	GAIN	ID	REC1	REC2	REP1	REP2	GBT	FAT	BTE	BTC
14	29	150	2.07	4.42	13.78	13.36	45.15	19.09	0.173	0.344	0.517	0.215
14	29	175	2.07	4.64	14.55	14.04	52.40	22.57	0.224	0.367	0.591	0.225
14	29	200	2.07	4.84	15.32	14.71	59.66	26.04	0.275	0.387	0.662	0.234
14	29	225	2.07	5.01	16.08	15.38	66.92	29.52	0.326	0.404	0.730	0.242
14	29	250	2.07	5.16	16.85	16.05	74.17	32.99	0.376	0.420	0.796	0.249
17	11	50	0.65	2.56	12.69	12.71	24.28	13.31	0.257	0.360	0.617	*0.085
17	11	75	0.65	3.14	13.62	13.52	31.53	17.53	0.308	0.420	0.728	*0.105
17	11	100	0.65	3.56	14.55	14.34	38.79	21.75	0.359	0.462	0.821	*0.119
17	11	125	0.65	3.88	15.48	15.15	46.04	25.97	0.410	0.495	0.905	*0.129
17	11	150	0.65	4.14	16.41	15.97	53.30	30.19	0.461	0.522	0.983	0.140
17	11	175	0.65	4.36	17.34	16.79	60.56	34.41	0.512	0.545	1.057	0.151
17	11	200	0.65	4.56	18.27	17.60	67.81	38.63	0.562	0.565	1.127	0.160
17	11	225	0.65	4.73	19.20	18.42	75.07	42.85	0.613	0.582	1.196	0.167
17	11	250	0.65	4.88	20.13	19.23	82.32	47.07	0.664	0.598	1.262	0.175
17	14	50	0.82	2.56	12.69	12.71	22.92	12.21	0.209	0.312	0.521	*0.085
17	14	75	0.82	3.14	13.62	13.52	30.17	16.43	0.260	0.372	0.632	*0.105
17	14	100	0.82	3.56	14.55	14.34	37.43	20.65	0.311	0.414	0.725	*0.119
17	14	125	0.82	3.88	15.48	15.15	44.68	24.87	0.362	0.447	0.809	*0.129
17	14	150	0.82	4.14	16.41	15.97	51.94	29.09	0.413	0.474	0.887	0.140
17	14	175	0.82	4.36	17.34	16.79	59.20	33.31	0.464	0.497	0.961	0.151
17	14	200	0.82	4.56	18.27	17.60	66.45	37.53	0.514	0.517	1.031	0.160
17	14	225	0.82	4.73	19.20	18.42	73.71	41.75	0.565	0.534	1.100	0.167
17	14	250	0.82	4.88	20.13	19.23	80.97	45.97	0.616	0.550	1.166	0.175
17	17	50	1.00	2.56	12.69	12.71	21.56	11.10	0.161	0.264	0.425	*0.085
17	17	75	1.00	3.14	13.62	13.52	28.81	15.32	0.212	0.324	0.536	*0.105
17	17	100	1.00	3.56	14.55	14.34	36.07	19.54	0.263	0.367	0.629	*0.119
17	17	125	1.00	3.88	15.48	15.15	43.33	23.76	0.314	0.400	0.713	*0.129
17	17	150	1.00	4.14	16.41	15.97	50.58	27.98	0.365	0.426	0.791	0.140
17	17	175	1.00	4.36	17.34	16.79	57.84	32.20	0.416	0.449	0.865	0.151
17	17	200	1.00	4.56	18.27	17.60	65.09	36.42	0.467	0.469	0.935	0.160
17	17	225	1.00	4.73	19.20	18.42	72.35	40.64	0.517	0.486	1.004	0.167
17	17	250	1.00	4.88	20.13	19.23	79.61	44.86	0.568	0.502	1.070	0.175
17	20	50	1.18	2.56	12.69	12.71	20.20	10.00	0.113	0.216	0.329	*0.085
17	20	75	1.18	3.14	13.62	13.52	27.45	14.22	0.164	0.276	0.440	*0.105
17	20	100	1.18	3.56	14.55	14.34	34.71	18.44	0.215	0.319	0.534	*0.119
17	20	125	1.18	3.88	15.48	15.15	41.97	22.66	0.266	0.352	0.617	*0.129
17	20	150	1.18	4.14	16.41	15.97	49.22	26.88	0.317	0.379	0.695	0.140
17	20	175	1.18	4.36	17.34	16.79	56.48	31.10	0.368	0.401	0.769	0.151
17	20	200	1.18	4.56	18.27	17.60	63.74	35.32	0.419	0.421	0.840	0.160
17	20	225	1.18	4.73	19.20	18.42	70.99	39.54	0.469	0.438	0.908	0.167
17	20	250	1.18	4.88	20.13	19.23	78.25	43.76	0.520	0.454	0.974	0.175
17	23	50	1.35	2.56	12.69	12.71	18.84	8.89	*0.085	0.168	*0.253	*0.085
17	23	75	1.35	3.14	13.62	13.52	26.10	13.11	0.116	0.228	0.344	*0.105
17	23	100	1.35	3.56	14.55	14.34	33.35	17.33	0.167	0.271	0.438	*0.119
17	23	125	1.35	3.88	15.48	15.15	40.61	21.55	0.218	0.304	0.522	*0.129
17	23	150	1.35	4.14	16.41	15.97	47.86	25.77	0.269	0.331	0.599	0.140
17	23	175	1.35	4.36	17.34	16.79	55.12	29.99	0.320	0.353	0.673	0.151
17	23	200	1.35	4.56	18.27	17.60	62.38	34.21	0.371	0.373	0.744	0.160
17	23	225	1.35	4.73	19.20	18.42	69.63	38.43	0.421	0.390	0.812	0.167
17	23	250	1.35	4.88	20.13	19.23	76.89	42.65	0.472	0.406	0.878	0.175
17	26	50	1.53	2.56	12.69	12.71	17.48	7.78	*0.085	0.120	*0.206	*0.085
17	26	75	1.53	3.14	13.62	13.52	24.74	12.00	*0.105	0.180	*0.285	*0.105
17	26	100	1.53	3.56	14.55	14.34	31.99	16.22	0.119	0.223	0.342	*0.119
17	26	125	1.53	3.88	15.48	15.15	39.25	20.44	0.170	0.256	0.426	*0.129

CW	DW	AMP	GAIN	ID	WEC1	WEC2	WEE1	WEE2	GMT	EAT	MTR	MTC
17	26	150	1.53	4.14	16.41	15.97	46.51	24.66	0.221	0.283	0.503	0.140
17	26	175	1.53	4.36	17.34	16.79	53.76	28.88	0.272	0.305	0.577	0.151
17	26	200	1.53	4.56	18.27	17.60	61.02	33.10	0.323	0.325	0.648	0.160
17	26	225	1.53	4.73	19.20	18.42	68.27	37.32	0.374	0.343	0.716	0.167
17	26	250	1.53	4.88	20.13	19.23	75.53	41.55	0.424	0.358	0.783	0.175
17	29	50	1.71	2.56	12.69	12.71	16.12	6.68	*0.085	0.072	*0.158	*0.085
17	29	75	1.71	3.14	13.62	13.52	23.38	10.90	*0.105	0.132	*0.237	*0.105
17	29	100	1.71	3.56	14.55	14.34	30.63	15.12	*0.119	0.175	*0.293	*0.119
17	29	125	1.71	3.88	15.48	15.15	37.89	19.34	*0.129	0.208	*0.337	*0.129
17	29	150	1.71	4.14	16.41	15.97	45.15	23.56	0.173	0.235	0.408	0.140
17	29	175	1.71	4.36	17.34	16.79	52.40	27.78	0.224	0.257	0.481	0.151
17	29	200	1.71	4.56	18.27	17.60	59.66	32.00	0.275	0.277	0.552	0.160
17	29	225	1.71	4.73	19.20	18.42	66.92	36.22	0.326	0.295	0.620	0.167
17	29	250	1.71	4.88	20.13	19.23	74.17	40.44	0.376	0.310	0.687	0.175
20	11	50	0.55	2.32	14.66	14.74	24.28	14.80	0.257	0.255	0.512	*0.077
20	11	75	0.55	2.91	15.76	15.70	31.53	19.77	0.308	0.315	0.623	*0.097
20	11	100	0.55	3.32	16.85	16.66	38.79	24.73	0.359	0.357	0.716	*0.111
20	11	125	0.55	3.64	17.95	17.62	46.04	29.70	0.410	0.390	0.800	*0.121
20	11	150	0.55	3.91	19.04	18.58	53.30	34.66	0.461	0.417	0.878	*0.130
20	11	175	0.55	4.13	20.13	19.54	60.56	39.63	0.512	0.440	0.952	*0.138
20	11	200	0.55	4.32	21.23	20.50	67.81	44.59	0.562	0.460	1.022	*0.144
20	11	225	0.55	4.49	22.32	21.46	75.07	49.56	0.613	0.477	1.091	*0.150
20	11	250	0.55	4.64	23.42	22.42	82.32	54.52	0.664	0.493	1.157	*0.155
20	14	50	0.70	2.32	14.66	14.74	22.92	13.70	0.209	0.207	0.416	*0.077
20	14	75	0.70	2.91	15.76	15.70	30.17	18.66	0.260	0.267	0.527	*0.097
20	14	100	0.70	3.32	16.85	16.66	37.43	23.63	0.311	0.310	0.620	*0.111
20	14	125	0.70	3.64	17.95	17.62	44.68	28.59	0.362	0.342	0.704	*0.121
20	14	150	0.70	3.91	19.04	18.58	51.94	33.56	0.413	0.369	0.782	*0.130
20	14	175	0.70	4.13	20.13	19.54	59.20	38.52	0.464	0.392	0.856	*0.138
20	14	200	0.70	4.32	21.23	20.50	66.45	43.49	0.514	0.412	0.926	*0.144
20	14	225	0.70	4.49	22.32	21.46	73.71	48.45	0.565	0.429	0.995	*0.150
20	14	250	0.70	4.64	23.42	22.42	80.97	53.41	0.616	0.445	1.061	*0.155
20	17	50	0.85	2.32	14.66	14.74	21.56	12.59	0.161	0.159	0.320	*0.077
20	17	75	0.85	2.91	15.76	15.70	28.81	17.56	0.212	0.219	0.431	*0.097
20	17	100	0.85	3.32	16.85	16.66	36.07	22.52	0.263	0.262	0.524	*0.111
20	17	125	0.85	3.64	17.95	17.62	43.33	27.49	0.314	0.295	0.608	*0.121
20	17	150	0.85	3.91	19.04	18.58	50.58	32.45	0.365	0.321	0.686	*0.130
20	17	175	0.85	4.13	20.13	19.54	57.84	37.41	0.416	0.344	0.760	*0.138
20	17	200	0.85	4.32	21.23	20.50	65.09	42.38	0.467	0.364	0.831	*0.144
20	17	225	0.85	4.49	22.32	21.46	72.35	47.34	0.517	0.381	0.899	*0.150
20	17	250	0.85	4.64	23.42	22.42	79.61	52.31	0.568	0.397	0.965	*0.155
20	20	50	1.00	2.32	14.66	14.74	20.20	11.48	0.113	0.111	0.224	*0.077
20	20	75	1.00	2.91	15.76	15.70	27.45	16.45	0.164	0.171	0.335	*0.097
20	20	100	1.00	3.32	16.85	16.66	34.71	21.41	0.215	0.214	0.429	*0.111
20	20	125	1.00	3.64	17.95	17.62	41.97	26.38	0.266	0.247	0.512	*0.121
20	20	150	1.00	3.91	19.04	18.58	49.22	31.34	0.317	0.274	0.590	*0.130
20	20	175	1.00	4.13	20.13	19.54	56.48	36.31	0.368	0.296	0.664	*0.138
20	20	200	1.00	4.32	21.23	20.50	63.74	41.27	0.419	0.316	0.735	*0.144
20	20	225	1.00	4.49	22.32	21.46	70.99	46.24	0.469	0.333	0.803	*0.150
20	20	250	1.00	4.64	23.42	22.42	78.25	51.20	0.520	0.349	0.869	*0.155
20	23	50	1.15	2.32	14.66	14.74	18.84	10.38	*0.077	0.063	*0.141	*0.077
20	23	75	1.15	2.91	15.76	15.70	26.10	15.34	0.116	0.123	0.239	*0.097
20	23	100	1.15	3.32	16.85	16.66	33.35	20.31	0.167	0.166	0.333	*0.111
20	23	125	1.15	3.64	17.95	17.62	40.61	25.27	0.218	0.199	0.417	*0.121

CW	DW	AMP	GAIN	ID	WEC1	WEC2	WEE1	WEE2	GMT	FAT	MTP	MTC
20	23	150	1.15	3.91	19.04	18.58	47.86	30.24	0.269	0.226	0.494	*0.130
20	23	175	1.15	4.13	20.13	19.54	55.12	35.20	0.320	0.248	0.568	*0.138
20	23	200	1.15	4.32	21.23	20.50	62.38	40.17	0.371	0.268	0.639	*0.144
20	23	225	1.15	4.49	22.32	21.46	69.63	45.13	0.421	0.286	0.707	*0.150
20	23	250	1.15	4.64	23.42	22.42	76.89	50.10	0.472	0.301	0.773	*0.155
20	26	50	1.30	2.32	14.66	14.74	17.48	9.27	*0.077	*0.030	*0.107	*0.077
20	26	75	1.30	2.91	15.76	15.70	24.74	14.24	*0.097	0.075	*0.172	*0.097
20	26	100	1.30	3.32	16.85	16.66	31.99	19.20	0.119	0.118	0.237	*0.111
20	26	125	1.30	3.64	17.95	17.62	39.25	24.17	0.170	0.151	0.321	*0.121
20	26	150	1.30	3.91	19.04	18.58	46.51	29.13	0.221	0.178	0.398	*0.130
20	26	175	1.30	4.13	20.13	19.54	53.76	34.10	0.272	0.200	0.472	*0.138
20	26	200	1.30	4.32	21.23	20.50	61.02	39.06	0.323	0.220	0.543	*0.144
20	26	225	1.30	4.49	22.32	21.46	68.27	44.03	0.374	0.238	0.611	*0.150
20	26	250	1.30	4.64	23.42	22.42	75.53	48.99	0.424	0.253	0.678	*0.155
20	29	50	1.45	2.32	14.66	14.74	16.12	8.17	*0.077	*0.030	*0.107	*0.077
20	29	75	1.45	2.91	15.76	15.70	23.38	13.13	*0.097	*0.030	*0.127	*0.097
20	29	100	1.45	3.32	16.85	16.66	30.63	18.10	*0.111	0.070	*0.181	*0.111
20	29	125	1.45	3.64	17.95	17.62	37.89	23.06	0.122	0.103	0.225	*0.121
20	29	150	1.45	3.91	19.04	18.58	45.15	28.03	0.173	0.130	0.303	*0.130
20	29	175	1.45	4.13	20.13	19.54	52.40	32.99	0.224	0.153	0.376	*0.138
20	29	200	1.45	4.32	21.23	20.50	59.66	37.96	0.275	0.172	0.447	*0.144
20	29	225	1.45	4.49	22.32	21.46	66.92	42.92	0.326	0.190	0.515	*0.150
20	29	250	1.45	4.64	23.42	22.42	74.17	47.89	0.376	0.205	0.582	*0.155

Number of Substitutions of GMT with MIN_GMT: 25

Number of Substitutions of FAT with MIN_FAT: 3

Number of Substitutions of MTC with MIN_GMT: 91

Total Conditions Predicted: 348

Appendix B

CONSENT FORM FOR PARTICIPATION

You are invited to participate in the human motor performance study conducted at the Human Factors Laboratory in the Psychology Department. Your participation in this study is voluntary, but you must be of legal age (18 years or older), and am legally competent to give this consent.

If you agree to participate, you will be seated in front of a monitor and a touch tablet. The target positioning task involves using a stylus (a ball-point pen) to point to the target area on the touch tablet. The study may help us better understand human motor performance in the future, but there will be no direct benefit to you.

All of the data collected will be kept strictly confidential. There will be no risk to you and your name will not be associated with your data. You will be given a copy of this consent form to keep.

This experiment will take one to two hours. You are free to withdraw from the experiment at any time, but then you will not receive extra credit points. No deception will be used. If you have any questions, please ask the experimenter now. If you have any additional questions later, you may reach Mr. Andy Parng at 677-5176.

____________________________ ____________
signature of participant date

____________________________ ____________
signature of witness date

Appendix C

INSTRUCTIONS FOR TARGET POSITIONING TASK: EXPERIMENTAL GROUP

The target positioning task involves moving the stylus held in your right hand on the touch tablet to position the cursor on the screen under a specified target area. At the beginning of each trial, you must first find the starting point on the screen and move the stylus to position the cursor on that point. Then you will notice the word "ready" will appear on the screen, and at the same time you will hear a "beep" sound. After the word "ready" appears, you can lift-off the stylus from the starting point on the tablet to point to the target area on the tablet. The cursor on the screen will provide you the feedback of your movements on the touch tablet. When you place the stylus back on the tablet, you have to decide whether the cursor is within the target area by looking at the screen. If the cursor is within the target area, you can lift-off the stylus from the tablet to end the trial. Otherwise, you have to maintain the stylus on the tablet, with a constant pressure, on the tablet surface while moving the stylus to control the cursor until the cursor is within the target area on the screen. After you move the cursor into the target area, you can lift-off the stylus to complete the trial. A "beep" sound will be heard at the end of each trial. There will be 24 blocks of trials in one session and each block consists of 15 consecutive trials. There will be two sessions in this experiment and you will have a ten-minute break between these two sessions.

** Please note:

1. You can take your time to prepare for each movement before the word "ready" appears. However, once the movement is initiated (i.e., the stylus is lifted off) you are asked to respond as quickly and accurately as possible.
2. You are required to look at the screen and aim at the target center line to make the responses. Only those responses made within the target area (target lines are included) will be considered as correct responses.
3. The touch tablet is very sensitive. Only a small amount pressure is needed.

Appendix D

INSTRUCTIONS FOR TARGET POSITIONING TASK: CONTROL GROUP

The target positioning task involves moving the stylus held in your right hand to point to a specified target area marked on the touch tablet. At the beginning of each trial, you must first find the starting point marked on the tablet and put the stylus on that point. Then you will notice the word "ready" will appear on the screen, and at the same time you will hear a "beep" sound. After the word "ready" appears, you can lift-off the stylus from the starting point on the tablet to point to the target area on the tablet. When you place the stylus back on the tablet, you have to decide whether the stylus is within the target area. If it is, then you can lift-off the stylus from the tablet to end the trial. Otherwise, you have to maintain the stylus on the tablet surface while moving it into the target area on the tablet. After you move the stylus into the target area, you can lift-off the stylus from the tablet to complete the trial. A "beep" sound will be heard at the end of each trial. There will be 24 blocks of trials in one session and each block consists of 15 consecutive trials. There will be two sessions in this experiment and you will have a ten-minute break between these two sessions.

** Please note:

1. You can take your time to prepare for each movement before the word "ready" appears. However, once the movement is initiated (i.e., the stylus is lifted off) you are asked to respond as quickly and accurately as possible.
2. You are required to aim at the target center line to make the responses. Only those responses made within the target area (target lines are included) will be considered as correct responses.
3. The touch tablet is very sensitive. Only a small amount pressure is needed.